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THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

OCTOBER 1922

SOCIETY OF AUTOMOTIVE ENGINEERS INC.
29 WEST 39TH STREET NEW YORK

Are You a Man for a Big Undertaking?

THERE are thousands of motorists—thousands right in your city and vicinity—who will eagerly pay $64.00 or three times that amount for the comfort, safety and economy results produced by Watson Stabilators.

But these motorists must be ***told about*** and ***shown*** these results. Someone in your city will now be given the opportunity of doing this—someone will now be granted the Stabilator Franchise.

Stabilator sales are fast and they pyramid. They pyramid because Stabilators are right.

They produce roadability results which are not equalled or even approached by any other spring-controlling device in the world.

The Franklin Automobile Company of Syracuse have gone on record as saying, "Watson Stabilators, the first real spring control we have ever seen."

The Stabilator market is limited only by the number of motor cars on the road. But the Stabilator Franchise is by no means easily had. Our requirements are very strict. It is generally conceded that the Stabilator Franchise agreement is the most strict document in the Automotive Industry. In short, the distribution of Stabilators is a very big job and only a very big man can handle it. Naturally, a very big man demands very big compensation, and there again Stabilators and the big man link up.

Stabilator Franchises are not given to Jobbers or to Car Dealers. We do not permit the handling of Stabilators in conjunction with any other articles. With an article such as Stabilators concentration of time and capital brings greatest returns.

If you and your friends are interested in a very big proposition and if you believe you have the qualifications for success in such an undertaking we shall be glad to hear from you. We would suggest your prompt action, but at the same time you are assured that we will close up with no man or association of men in your city until we are satisfied that we are dealing with the best outfit.

JOHN WARREN WATSON COMPANY
Twenty-Fourth and Locust Streets
Philadelphia, Pa.

Look for the Silver Nawe Plate

Exactly opposite to snubbing

In checking spring recoil, Stabilators work exactly opposite to the snubbing principle. Instead of checking with a jerk at the tail end of the recoil movement, Stabilators get on the job at the very beginning of the movement and smoothly ease you back to normal. Results produced by the one method give no conception of those produced by the other. They are different to the point of absolute opposiiteness.

WATSON STABILATORS

CHANGE THE WHOLE NATURE OF YOUR CAR

THE JOURNAL OF THE SOCIETY OF AUTOMOTIVE ENGINEERS

Vol. XI October, 1922 No. 4

Chronicle and Comment

The Production Meeting

THE success of the Society's first National Production Meeting seems assured. Although production executives are an extremely busy group of men at this time, they are showing interest in the program, preparing papers and arranging factory visits. The papers will cover labor-control systems, variations in gear-tooth generation, gear noise resulting from faulty mounting, cylinder production from the ore through to the engine assembly and other equally instructive subjects. A special *Meetings Bulletin* will reach the members about Oct. 15, with all final details of the program. Progress in the arrangements is reported on p. 373 of this number of THE JOURNAL. Make your plans to visit Detroit on Oct. 26 and 27.

The Sections Meetings

THE Sections of the Society open their season of meetings activity in earnest with the coming of October. Meetings are scheduled in all of the Section centers. Programs are varied and cover a wide field. Metal airplanes, research, petroleum refining, wire and disc wheels, steel bodies and road-testing are among the subjects listed for discussion. Interest in the Sections meetings appears greater than ever before. If you have not taken advantage of this privilege of your membership you are losing one of the major benefits of association with the Society. Turn to p. 380, note the imposing list of October meetings and attend the one in or nearest your home city.

The Employment Service

THERE have been 70 men placed in positions in the automotive industry since April 1 by the Employment Service of the Society. One can appreciate the value of this service to the members and the industry when it is recognized that a large majority of these positions are classed as executive and carry responsibility. A semi-weekly bulletin of positions available is mailed to every applicant for employment. A semi-weekly bulletin of men seeking positions is sent to a selected list of representative firms for their information. The service is probably the only one of its kind specializing in the automotive field, and is free to both employer and employe. Men are placed in all divisions of the industry; sales, production, service, research and engineering. When you are in need of an executive with training suited to a particular line of automotive work, be sure to consult the Society's Employment Service.

Fuel and Engine Developments

IT is well recognized that the production of crude oil has not increased as rapidly as the demand for it, and that the demand for gasoline would not have been met if the oil industry, on the one hand, had continued to supply the very volatile gasoline produced 5 to 10 years ago, or if the automotive industry, on the other hand, had continued to build engines, carbureters and other equipment adapted to only those lighter fuels. Both industries have developed progressively; the oil industry by increasing the gasoline yield through taking a larger fraction of the barrel of fuel, that is, by making heavier gasoline by "cracking," and by the use of casinghead or natural gasoline, and the automotive industry by directing its energies to designing engines and other equipment that would use heavier gasoline to better advantage.

The 1923 Summer Meeting

WHERE shall the Summer Meeting of 1923 be held? This important question is deserving of the most careful consideration by the members of the Society. Those who attended the recent meeting at White Sulphur Springs pronounced it the ideal location for the Society's future summer gatherings. On the other hand, one continually hears criticism of this type of meeting place in conjunction with a demand for a return to the boat trip on the Great Lakes. The 1922 Summer Meeting did not attract as large a number of the members engaged in engineering and design work as seemed desirable. Was it the location, or do these men favor a variation in the type of meeting? These are perplexing questions and the Meetings Committee and the Council are desirous of receiving the opinions of members to guide them in selecting a location and defining the plan of the 1923 meeting. Please address letters on this matter to the Society's office in New York City and they will be referred to the Meetings Committee.

Motor-Fuel Quality

THE volatility of motor gasoline as reported by the Bureau of Mines, as a result of its semi-annual motor-gasoline survey, has improved slightly over that reported 6 months ago. Up to about 2 years ago

motor-fuel quality showed a steady decline; since that time the quality has been improving steadily, contrary to the popular impression.

Of perhaps greater importance to the user is the fact that the *uniformity* as well as the quality is improving. In other words, supplies of gasoline bought at different filling-stations or at different times vary much less than formerly. The Bureau of Mines' report states that the differences between Winter and Summer gasoline is still maintained by the refiners. The difference in volatility is made intentionally to facilitate starting in cold weather.

Comparing the distillation curve of the average gasoline sold throughout the Country in July 1922, as determined by the Bureau of Mines with the Federal specifications on which all motor gasoline is purchased by the Government, it is found that the average commercial gasoline is considerably better than the Government requirements, except for a small range where the two curves are identical.

Service

ABSTRACT definitions of "Service" include: Provision for the carrying out of work for which there is a constant public demand; an agency for meeting a general or recurrent need.

At the last meeting of the Society, F. A. Bonham, on behalf of the Service Committee of the National Automobile Chamber of Commerce, discussed the relationship of engineering to service in connection with the maintenance of motor vehicles. He expressed the opinion that automotive engineers in general do not understand adequately the real basis of such service. He stated that the demand for properly trained and conscientious automobile mechanics so far exceeds the supply that unsatisfactory repairmen will have to be accepted by the industry for a number of years.

The demand is for repairs and the replacement of parts promptly and at low cost. Standard repair operations are being developed. The "flat rate" is in vogue, an advance quotation of the cost of repairs being based on it. But, Mr. Bonham pointed out, the limiting factor of the whole operation of service is design. The engineer's product is operated and repaired by persons who do not know much about it. The resultant expense of carelessness and incompetence, as well as of deficient design, must be borne.

The service problem is an inherent part of design. Mr. Bonham said that major considerations are:

(1) Sequence of operations in manufacture and assembly, as affecting the making of repairs
(2) Dismounting of assembly units by the use of simple tools
(3) Low cost of wearable parts
(4) Design of simple tools for making repairs
(5) Dependability of constituent mechanisms of complete apparatus

The greatest possible simplicity and accessibility of parts are of course essential. Thought must be given assiduously to what the repairman has to do in his work. Service Departments obviously can furnish much valuable information on the whole matter of maintenance necessities and conveniences. Mr. Bonham believes that a comprehensive thorough study of service conditions will have a far-reaching effect on automotive design. The task is to minimize the effect of the inevitable abuse of machines by users and of the carelessness and incompetence of repairmen.

It was urged that engineers do everything possible to make newly designed or changed parts interchangeable with corresponding parts in old car models, as this will reduce greatly the burden of the service-stations in supplying replacement parts. The engineer has a responsibility to the public equal to that of anyone in the industry. The dealer and the serviceman are entitled to his best efforts. The reduction to practice of "pet" engineering theories should not be tolerated if this involves experimentation or unreasonable servicing. This is fundamentally important from the standpoint of unjustified major expense. Ease and low cost of maintenance and repair must be borne in mind constantly.

SEPTEMBER COUNCIL MEETING

THE meeting of the Council held on Sept. 19 at New York City was attended by President Bachman, Vice-Presidents Segner and Brautigam, Councilors Crane, Davis, Scott and Smith, Past-President Beecroft and Treasurer Whittelsey. H. W. Alden, A. J. Scaife and E. P. Warner, nominees for the 1923 Council, also attended.

The financial report as of July 31 showed a net balance of assets over liabilities of $121,863.37, this being $18,114.37 less than the corresponding figure on the same day of 1921. The income of the Society for the first 10 months of the current fiscal year amounted to $137,523.87. The operating expense during the same period was $154,290.99.

A budget for the fiscal year beginning Oct. 1, 1922, was adopted. This budget anticipated an income for the 1923 fiscal year of $268,585.25, and expenses of the same amount.

Fifty-nine applications for individual membership were approved. The following transfers in grade of membership were approved: From Junior to Member, H. W. Simpson, D. T. Stanton, Quentin Twachtman; Associate to Member, O. J. Rohde, Peter M. Erikson.

It was reported that up to Sept. 18, 1922, 546 applications for membership had been received, as compared with 576 received during the first 9 months of 1921, and 946 during the first 9 months of 1920. On Aug. 31 there were 5685 names on the rolls of the Society, including affiliate member representatives and enrolled students, as compared with 5609 on the same day of 1921 and 4781 on the same day of 1920.

The appointment of Archibald Black as member of the Aeronautical Safety Code Sectional Committee and Chairman of Subcommittee 3 on Equipment and Maintenance of Airplanes was approved.

It was reported that since April of this year 68 members have notified the Society office that they have secured positions through the S. A. E. Employment Service. No doubt many others have been placed but failed to mention the fact.

The next meeting of the Council has been scheduled to be held in Detroit on Oct. 25, previous to the Production Meeting on the 26th and 27th.

Vaporization of Motor-Fuels

By P. S. Tice[1]

Mid-West Section Paper *Illustrated with* Photographs and Charts

THE author gives a brief and purely qualitative treatment of what a vapor is, where it comes from and how it appears; the necessity of vaporizing a liquid fuel before attempting to burn it; the separate effects of the conditions that control vaporization; and the heat-balance of vaporization. This is done to summarize the conditions surrounding and controlling fuel vaporization in the cycle of operation of a throttle-controlled internal-combustion engine, fitted with an intake-manifold and a carbureter. Charts and photographs are included and commented upon, descriptions being given of actual demonstrations that were made at the time the paper was presented. The conclusion is reached that it is well to depend as little as possible upon the cylinder heat and temperature to complete the vaporization of the fuel.

THE purpose of this paper is to summarize the conditions surrounding and controlling fuel vaporization in the cycle of operation of a throttle-controlled internal-combustion engine, fitted with an intake-manifold and a carbureter. The procedure by which it is hoped to arrive at a reasonably clear and comprehensive picture of the relative values and relations of these conditions will include: (*a*) a description of what a vapor is, where it comes from and how it appears; (*b*) a demonstration of the necessity of vaporizing a liquid fuel before attempting to burn it; (*c*) a statement, with descriptions of actual demonstrations, of the separate effects of the conditions that control vaporization; and (*d*) a discussion and description of actual demonstrations of the heat balance of vaporization. These items will be given only brief and purely qualitative treatment. Generalizations dealing with the effects of impure or mixed fuels will be introduced and an attempt made to show the advantages and limitations of an engine's intake system as an environment in which to stage the vaporization process.

Vapor and Vaporization

A vapor has been defined as a gaseous or elastic fluid phase of a volatile liquid at or near its condensation point, or below its critical point so that it can be liquefied by pressure alone; evaporation, as the change by which a substance is converted from the liquid state into, and carried off in, the vapor state; and a volatile liquid, as one that evolves vapor rapidly at ordinary temperatures.

The two terms evaporation and vaporization are commonly used interchangeably, and no sharp distinction can be drawn between them. However, it is convenient to consider the formation of vapor under natural conditions as evaporation, and vaporization as the act or process of forming a vapor by subjecting a liquid to artificially modified conditions that hasten its evaporation. From the molecular standpoint, vaporization or evaporation means the flying off of molecules against the forces of molecular attraction at the surface of the liquid, the molecules losing kinetic energy and gaining potential energy as they leave the liquid surface. The liquid and the vapor of any substance have identical compositions, and differ only in state. This is a short way of saying that the only difference is that of molecular aggregation or closeness of grouping of the molecules.

A simple demonstration with a rudimentary flash-point apparatus will serve to show that the talk of the carbureter people about the virtues of vaporization is not wholly unwarranted. To demonstrate this let us consider four tubes in which have been placed (*a*) gasoline; (*b*) gasoline from which the most volatile constituent has been removed; (*c*) kerosene; and (*d*), nothing; in other words, the last tube is a barometer. The differences between the height of mercury in the barometer and in each of the other tubes containing fuel measure the relative volatilities of the fuels. Samples of each of the three fuels, cooled to about 0 deg. fahr., are placed in three small covered beakers in the same order as in the tubes and sparks are caused to pass continually over their surfaces until combustion starts. This will occur as soon as the fuels have attained temperatures at which vapor is given off at a rate to support combustion, and the three fuels will start to burn in the order of their volatility.

Such a demonstration suggests four very important things: (*a*) the striking differences in volatility that obtain among liquid fuels; (*b*) that fuels will not burn in the liquid state; (*c*) that vapor must be present in quantities to support combustion; and (*d*) that the greater the proportion of the vapor to the liquid in a given space, the more rapid the combustion will be, provided there is sufficient oxygen present to support it.

Conditions Controlling Vaporization

It is a matter of common experience that evaporation is retarded and finally ceases if the vapor is confined at the liquid surface. This is shown in each of the barometer tubes containing only a liquid and its vapor, and in which the heights of the mercury have been constant for some time. It then becomes evident that the evolution of vapor has stopped. The reason that evaporation stops in such a case is that some of the molecules of the vapor, in their normal motions, strike the surface and join the liquid again; and, as the number of vapor molecules in a given space increases, due to the increased density of the vapor, the number of molecules so returning to the liquid in a given time will likewise increase, until finally the average number returning to the liquid will equal the average number leaving it. Under this condition the vapor is in equilibrium with the liquid.

When this equilibrium condition is reached, the space above the liquid is said to be saturated with vapor; and the density, and therefore the pressure, of the vapor are then the maxima that can exist in the presence of the liquid at the temperature of the experiment. This maximum pressure is called the saturation pressure. Proof that this pressure is the maximum that can exist is afforded by shifting the leveling bulb that forms a part of the demonstrating apparatus. The only result will be to change the vapor volume. The pressure remains constant as shown by the fixed difference in height

[1] M.S.A.E.—Engineer directing the carbureter division, Stewart-Warner Speedometer Corporation, Chicago.

of the mercury columns. The value of this pressure depends only upon the temperature; that is, upon the average molecular velocity of the liquid, and is unaffected by the presence of any non-combining gas or vapor. This is strictly true only for single liquids such as water or benzol. With mixed liquids such as gasoline the pressure or the temperature changes somewhat with changes in the volume of the vapor space.

Evaporation is accelerated by passing a current of air over the surface of a liquid, or by any expedient that removes the vapor from the liquid surface. This is demonstrated by the high rate of evaporation when a small stream of air is used to sweep the vapor away from the liquid surface. Since the vapor is not allowed to accumulate, it must remain unsaturated, equilibrium cannot be reached, and the liquid disappears by evaporation.

The vapor-pressure, a term denoting the saturation-pressure when used without qualification, invariably increases rapidly with a rise of temperature. A rise of pressure occurs as the temperature of the liquid is raised gently by heat from a small resistance-coil wound around the tube in which the liquid is contained. A rise of temperature is another way of saying that the molecules are moving faster; the faster the liquid molecules move the more numerous are those that fly off from the surface. To keep the liquid in the tube where heat can be applied directly to it, the leveling bulb must be raised. The change in pressure is measured by the height through which the bulb is raised.

If the temperature of a liquid is raised sufficiently to cause its vapor-pressure to become equal to the external pressure, vapor bubbles form freely in the interior of the mass of liquid, by the well known process of boiling. The temperature at which this occurs, under standard atmospheric pressure, is called the boiling-point.

When a flask contains fairly hot water and is in open communication with the atmosphere, the water is at a high enough temperature to exert a vapor-pressure nearly equal to that of the atmosphere. A further rise of temperature, which can be brought about by setting the flask on a hot plate, results in the formation of vapor bubbles as soon as the pressure of the water vapor equals that of the atmosphere.

If the external pressure remains constant, the temperature of a pure boiling liquid will remain constant at its boiling-point, while the liquid passes off by vaporization. When water at sea level boils vigorously, a thermometer inserted in it will continue to register 212 deg. fahr. as long as the boiling continues. It is evident that water in the vapor state is leaving the surface and does not return to it. But, if the liquid is contained in a closed space, it can be made to boil at temperatures below its normal boiling-point by reducing the pressure. This is made evident when the liquid in the vapor tube is allowed to cool slightly below its normal boiling-point. If the pressure in the tube is reduced, as is the case when the leveling bulb is lowered, the liquid will boil again at its now reduced temperature, as indicated by the bubbles seen to form in it. The same phenomenon can be shown by removing from the hot plate the flask in which water is boiling, sealing it and applying ice to the vapor space above the liquid. In this case the ebullition will be more spectacular than in a tube, because the mass of liquid is greater and the pressure can be reduced conveniently to a much lower value. As the boiling progresses, the temperature will drop rapidly. Removal of the ice, the presence of which causes the pressure reduction, will stop the boiling, while the replacement of the ice will cause the boiling to start again. The boiling may be made to continue until the temperature of the liquid is about 20 deg. fahr. below that of the room.

Correspondingly, if the pressure is raised, the temperature of a liquid must be raised above its normal boiling-point to secure ebullition. There is for every temperature a corresponding equilibrium or saturation-pressure of the vapor, and vice versa. But the temperature and pressure cannot be raised indefinitely. As the temperature is raised, the density of the saturated vapor increases, while that of the liquid decreases. If the temperature is raised sufficiently, the densities of the liquid and of its vapor become equal at a definite temperature depending upon the substance. This temperature is called the critical temperature, because it is the limiting temperature at which a separation of the liquid and the vapor states can be observed. If we seal a liquid and its vapor in a small tube and raise the temperature of the tube, a point will be reached at which it will be impossible to distinguish between the liquid and the vapor. Reducing the density of the liquid causes its upper boundary to rise until the liquid completely fills the tube. All parts of the tube are now shared equally by the liquid and its vapor. When the temperature drops, the tube, from bottom to top, becomes filled with a fog of reaggregated molecules, and the meniscus separating the two states rapidly settles as the density of the liquid increases.

At temperatures above the critical temperature there is what is known as continuity of state, since it is impossible to cause separation of the two states by modification of the pressure alone. Attention is directed to Fig. 1, which is a plot of isotherms on pressure-volume coordinates for carbon dioxide. The properties shown in this graph are characteristic of all substances. It is a plot of the typical pressure-volume relations of a substance at temperatures below and above the critical value. The horizontal portions of the isotherms enclosed by the dotted curve show the characteristic change of state, from liquid to vapor, or vice versa, at constant pressure and constant temperature. To the right of the horizontal portions, the substance is completely vaporized and behaves like a gas. To the left, it is all liquid. Note that as the critical temperature is approached there is a continually smaller change of volume between the all-liquid and all-vapor conditions. This illustrates a statement to be made later to the effect that the latent heat becomes less with increased temperature, and at the critical temperature has a zero value.

The two controlling factors in the process of vaporization are the temperature of the liquid and the vapor-pressure exerted on its surface. Raising the temperature at a constant vapor-pressure, or lowering the vapor-pressure at a constant temperature, or doing both simultaneously, causes a further evolution of vapor from the liquid. This is the sole means available for accelerating the vaporization of a liquid.

The controlling pressure in vaporization is only the pressure exerted by the vapor upon the liquid surface. A demonstration of the fact that the saturation pressure of a vapor is unaffected by the presence of any non-combining gas or vapor makes clear what is meant by the term partial pressure. This can be done by using a normal barometer tube devoid of air above the mercury. If a small quantity of liquid is introduced into this tube, its vapor at once fills the space above the mercury, and the mercury column falls an amount proportional to the vapor-pressure of that liquid at the prevailing temperature. When a vapor-pressure tube from which all air has been expelled, is used as a barometer, if the tube cock is opened,

an amount of air admitted, the tube resealed, and the bulb returned to its former position at which the barometric height was shown, the pressure above the mercury will be higher than before. The difference between the new height of the mercury column and the barometric height is a measure of the pressure due to the air in the tube. If, now, we introduce into this tube some of the same liquid that was put into the conventional barometer tube, and set the leveling bulb so that the volume above the mercury in the tube is the same as before the liquid was admitted to it, it will be found that the pressure-rise due to the vapor in the tube containing air is exactly the same as that in the first barometer tube which contained no air when the liquid was put in.

This shows that a given equilibrium-pressure exists for a given liquid at a given temperature, whether that vapor-pressure is the total pressure exerted on the liquid surface, or it is only a part of the total pressure so exerted. The only difference to be noted in the two cases is that the equilibrium pressure is attained much more rapidly when only the vapor occupies the space above the liquid. The molecules of a gas interfere with the free dispersion of the vapor molecules, causing a greater average vapor density at the surface of the liquid in one case than in the other.

When a vapor is in equilibrium with its liquid and the vapor exerts only a fraction of the total pressure, a change of pressure of the total fluid above the liquid, such as is produced by a change of volume, will change the pressure of the vapor in a like ratio and destroy the equilibrium relation. But, if the temperature of the liquid is kept constant, equilibrium will become reestablished at exactly the same vapor-pressure as before. Depending upon whether the volume is increased or decreased to change the total pressure, the partial pressure of the vapor, and therefore the relative vapor-content of the space, will become correspondingly greater or less. This is a matter of great importance in the practical carburetion of an engine, as will be shown later.

Heat Balance of Vaporization

The conception of heat as a form of energy, the common manifestation of which is temperature, is familiar to everyone. Degrees of temperature represent intensities of heat and not quantities of heat, because, when equal quantities of heat are imparted to two bodies of equal mass but of unlike substance, one is found to be hotter than the other. The specific heats of the two substances are then said to be different, the one showing the higher temperature having the smaller specific-heat capacity. Besides raising the temperature, heat usually causes an increase of volume. Part or the whole may go toward producing changes of state by fusion or vaporization and may cause chemical reactions. Part may also be transformed into other forms of energy, producing the phenomena of light, electricity and the like. Heat may be imparted to a body (*a*) by conduction, as along a metal rod; (*b*) by convection, as through the rooms of a house by air currents; and (*c*) by radiation, as from the sun to the earth.

To convert a substance from a liquid to a vapor without change of temperature, it is necessary to impart to it a certain amount of heat. The quantity of heat so required per unit mass of the liquid is the latent heat of vaporization. It is called latent because it causes no temperature-rise and disappears, so far as our senses are concerned, in performing the change of state. Since vaporization of a liquid produces a great increase in volume, which acts against a definite pressure, external work must be done by the vapor as it is formed. In the performance of this work the heat disappears or becomes latent, as was demonstrated by the water in the flask set on a hot plate boiling without any change of temperature. The latent heat of vaporization diminishes with increasing temperature, and becomes zero at the critical temperature, where the distinction between a liquid and a vapor vanishes.

The total heat of vaporization of a saturated vapor at any temperature is the quantity of heat required to raise a unit mass of the liquid from any convenient zero to the temperature in question, and then to evaporate it at that temperature under the constant corresponding pressure of saturation. If, instead of converting a liquid into its vapor, we reverse the process or condense the vapor into its liquid, and bring the temperature of the recovered liquid back to the value from which it was initially raised, the total heat of vaporization is recovered and transmitted from the liquid to some other body.

Let us take two bulbs, sealed to each other in the form of an inverted U, and containing only water and its vapor. The water is all in the outside bulb, and the other one, immersed in the beaker, contains only water vapor. Applying heat to the exposed bulb causes the water to vaporize, making heat latent in so doing. The vapor thus evolved is condensed in the other bulb, in which liquid begins to appear. Upon condensation of the vapor, the heat that was latent in it reappears and is taken up by the walls of the bulb and the air in the beaker surrounding it. That heat will reappear at the bulb immersed in the beaker can be made evident from observation of the convection currents set up in a liquid poured into the beaker and the vapor coming off that

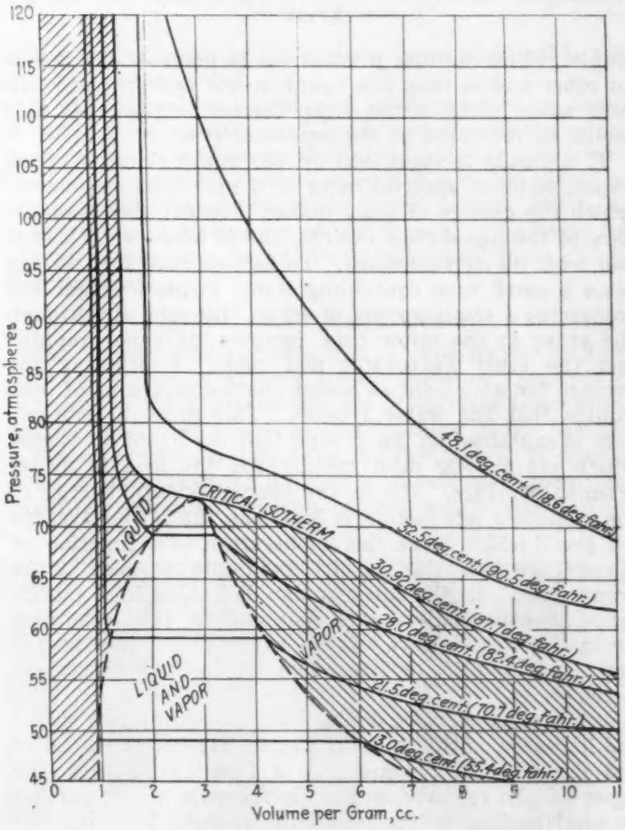
Pressure, atmospheres
Volume per Gram, cc.
48.1 deg. cent. (118.6 deg. fahr.)
CRITICAL ISOTHERM
32.5 deg. cent. (90.5 deg. fahr.)
30.92 deg. cent. (87.7 deg. fahr.)
29.0 deg. cent. (82.4 deg. fahr.)
21.5 deg. cent. (70.7 deg. fahr.)
13.0 deg. cent. (55.4 deg. fahr.)
LIQUID
VAPOR
LIQUID AND VAPOR

Fig. 1—Series of Curves Showing the Typical Pressure-Volume Relations of a Substance at Temperatures Above and Below the Critical Value

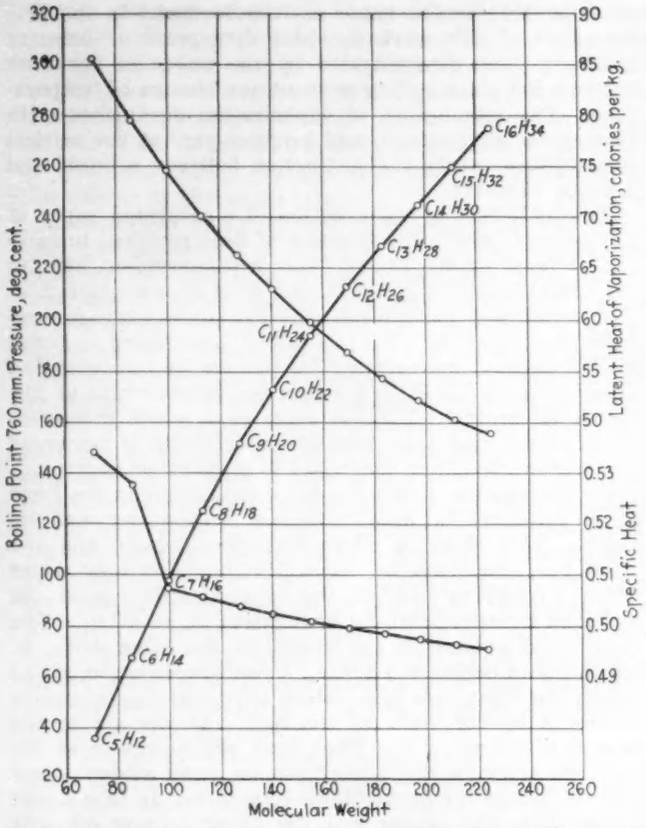

FIG. 2—GROUPING OF PHYSICAL CONSTANTS REFERRED TO MOLECULAR WEIGHT FOR THE MEMBERS OF THE PARAFFIN SERIES FOUND IN OUR FUELS

liquid. With suitable precautions to prevent loss of heat to other bodies than the liquid in the beaker, the whole heat made latent in the vapor formed in the outer bulb would be recovered at the immersed one.

If a liquid is vaporized by the rapid removal of its vapor, without applying heat at a rate equal to that at which the change of state makes it latent, the temperature of the liquid falls rapidly, and it takes what heat it can from its surroundings. To demonstrate this we can place a small tube containing water inside a larger one containing a small amount of ether. Blowing air through the ether in the outer tube removes its vapor rapidly, and the ether evaporates and cools. Continuing the process for a moment so lowers the temperatures of both liquids that the water freezes. This drop in temperature is explained on the ground that the liquid molecules, which are moving most rapidly, are the first to fly off from the surface. Hence, the average kinetic energy of the molecules left behind is less than the initial average for the liquid. Since the temperature is a function of the average molecular velocity, the liquid is cooled by the evaporation. In the cases of liquids having high latent-heats of vaporization, it is possible by this means to lower the temperature of the vaporizing liquid so far that it will solidify or freeze long before its vaporization is complete.

Again using a sealed double bulb containing only water and its vapor, if the water is all run into one of the bulbs and the other is plunged into a freezing mixture, the vapor will be removed so rapidly from the water surface by condensation in the cold bulb, thereby reducing the vapor-pressure throughout, that the temperature of the water in the exposed bulb will drop to the freezing point and the water will solidify into a cake of ice. This apparatus is called a cryophorus, from the fact that when it is treated in this manner it bears frost.

The points it is desired to make are: (*a*) that vaporization is accomplished only as a result of the application of heat; and (*b*) that the vaporization of a given quantity of a given liquid requires a definite amount of heat, no matter how the other conditions by which the process is surrounded may be altered.

MOTOR-FUELS ARE HETEROGENEOUS MIXTURES

All present-day motor-fuels are mixtures of a great number of substances. Each component has, of course, its own particular heat of vaporization and vapor-pressure. Fortunately for both producer and consumer, the vapor-pressures of these mixtures agree very closely with that of the most volatile constituent. The result is that, if we pump enough fuel into an engine, we can get it started on the trace of volatile material in the fuel. Attention is directed to the result with the two kinds of gasoline in the first demonstration.

The specific heats do not vary greatly among fuels or their constituents. Among petroleum fuels latent-heat values decrease with decreasing volatility. Naturally, the less volatile the fuel components are, the higher will be the temperature at which a given relative vapor-density is attained. Assuming that our interest is in the maintenance of a given rate of vaporization of the fuel, this fact entirely overshadows the advantage that might be expected from a consideration of the latent heats alone. Not only is a greater total heat needed to vaporize a less volatile fuel but less heat is made latent in the process. As the fuel becomes less volatile, the normal intake temperature in an engine will of necessity increase if a given relative vapor-content is to be maintained in the charge. The relations of the pertinent physical constants of the majority of the paraffin petroleum compounds appearing in motor fuels are shown in detail in Figs. 2 and 3.

Fig. 2 is a grouping of physical constants referred to molecular weight, for the members of the paraffin series found in our fuels. These values have been taken from the work of C. F. Mabery and A. H. Goldstein.[2] Fig. 3 shows an interesting heat relation developed from the values shown graphically in Fig. 2. The facts here presented are: (*a*) the great increase in total heat of vaporization in the face of lowered values of the latent heat accompanying reduced volatility; and (*b*) the enormous increase in the sensible heat expressed as a fraction of the total heat, as the volatility is reduced. When it is considered that within the last 5 or 6 years the mean characteristics of our motor gasoline have shifted from those of hexane C_6H_{14} to somewhere in the immediate neighborhood of those of octane C_8H_{18}, the reasons for our need to apply more heat and to maintain higher charge temperatures are explained somewhat by this graph.

VAPORIZATION IN THE ENGINE INTAKE

To apply the facts that have appeared thus far, and to relate them to the conditions in the intake system of an engine, it is necessary only to examine those peculiarities of the intake that modify the rate of evolution of vapor. The simplest way to do this is to follow the fuel from the carbureter nozzle to the cylinders. As soon as the fuel issues into the airstream, some of its molecules fly off into the gas space, in numbers depending upon the temperature of the fuel. Since the partial pressure due to the fuel vapor is zero, or at least is negligibly small, the number of molecules leaving a unit surface in a unit

[2] See *American Chemical Journal*, vol. 28, pp. 66 and 165.

time is no doubt the maximum possible at that temperature of the liquid.

Let us imagine two fuel-sprayers passing fuel at the same rate and temperature, the only difference between them being that one causes twice the initial liquid-surface exposure as the other. It is evident that twice the number of molecules will fly off into the gas space in one case as in the other. A very important expedient for accelerating the rate of vaporization is indicated here; and it can be stated that the initial rate of vaporization is directly proportional to the extent of the liquid surface exposed. But, as we have seen, heat disappears in doing the work of vaporization. Thus, from the first instant of issuance into the air-filled space, the temperature of the liquid will fall unless a suitable quantity of heat is imparted to it.

If twice the number of molecules fly off initially from the liquid discharged from one fuel sprayer as from the other, it is evident that a suitable quantity of heat to maintain the temperature of the liquid must be imparted at twice the rate in one case as in the other. The quantity of heat used in vaporizing a given amount of liquid fuel is the same in both cases; but, to maintain constancy of temperature, the rate of heat supply must be in direct ratio with the area of the liquid surface exposed. If heat is not supplied to maintain the temperature, it follows that the initial rate of heat loss from the liquid fuel will be twice as great in the case of the sprayer in which twice the surface is exposed. Since the temperature varies as the heat-content of a body, it is seen that the initial rate of temperature drop in the liquid fuel is in direct proportion to the surface exposed.

Allowing the temperature to fall in this way lowers the saturation-pressure and so causes a nearer approach to equilibrium between vapor and liquid, with a consequent reduction in rate of vaporization. Considering the discharges of the two sprayers, if no external heat is applied it is evident that equal drops in temperature mean equal amounts of fuel vaporized, and that ultimately the temperatures and the vapor-densities will be the same. But there is no time for dalliance in the intake of a modern engine; and so it is that, within the time available in the system, greater extension of the fuel surface causes a greater lowering of the temperature and also accounts for a greater vapor-density in the charge.

Let it now be supposed that the initial rate of vaporization is insufficient, and that heat is applied in excess of that needed to maintain the initial fuel-temperature. The saturation-pressures are then raised, the equilibrium condition is deferred and the rate of vaporization is accelerated in consequence. But the rate of passage of heat into a body varies directly with its exposed surface; and the rate of vaporization varies directly with the rate at which heat is taken on. Thus it is seen that the sustained rate of vaporization is directly proportional to the liquid surface exposed.

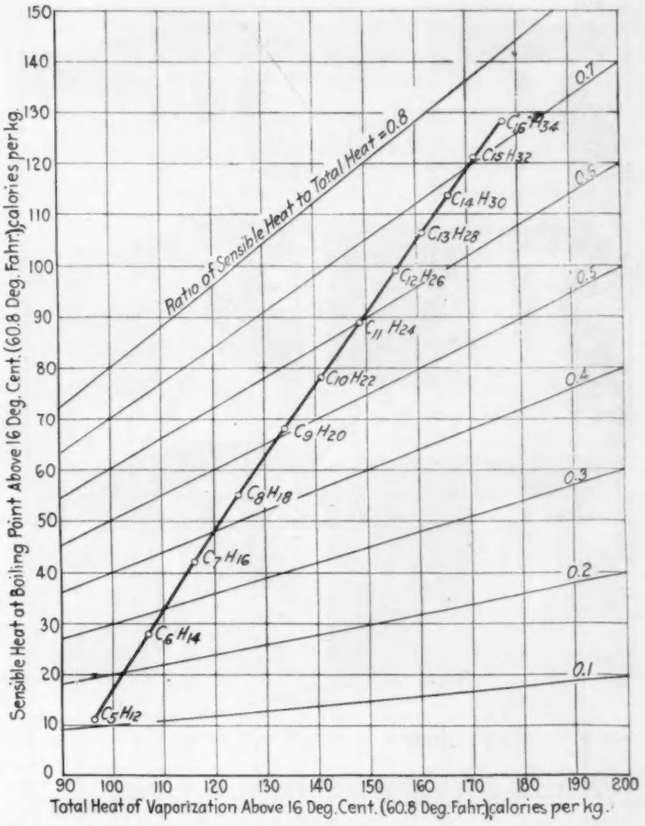

FIG. 3—RELATIONSHIP OF THE TOTAL HEAT OF VAPORIZATION TO THE SENSIBLE HEAT

In the case of an engine and intake system arranged to apply such an excess of heat that the final charge-temperature is well above the initial temperature of the fuel, as in a typical modern engine, the direct result of an appreciable extension of the liquid surface will be to increase the vapor-density of the charge, or to lower the charge-temperature, or to accomplish both these things simultaneously.

EFFECT OF INTAKE PRESSURE

The general effect of pressure on vaporization will not require discussion at this time. However, *changes of pressure in the engine intake are of extreme importance*, particularly those following manipulation of the throttle.

Let us suppose an engine to be throttled, as in driving a car within the speed limit on a smooth level road. The manifold pressure is then approximately one-half an

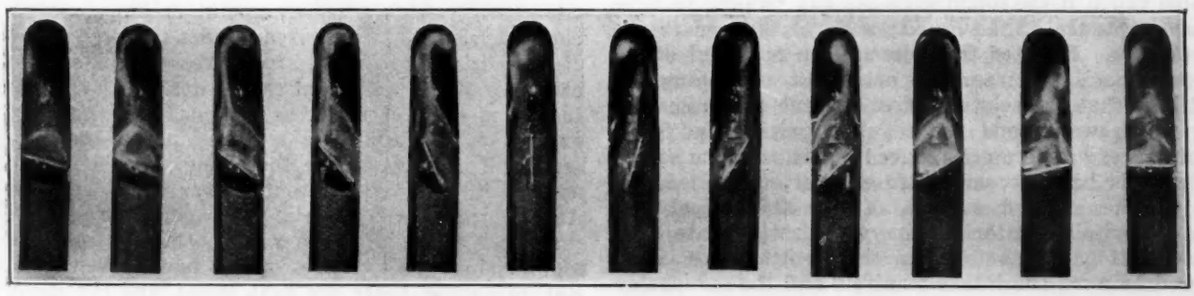

FIG. 4—SERIES OF PHOTOGRAPHS SHOWING THE ACTION THAT TAKES PLACE IN THE INTAKE-MANIFOLD AT AND ABOVE THE THROTTLE AS ITS POSITION IS CHANGED FROM CLOSED TO FULL OPEN AND BACK TO CLOSED

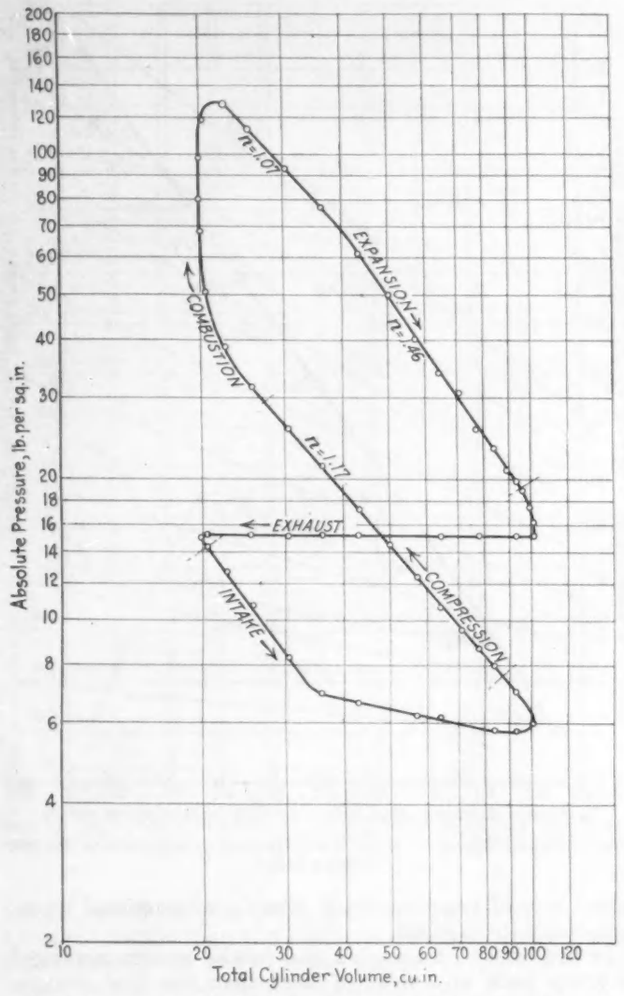

FIG. 5—TYPICAL PART-THROTTLE INDICATOR-CARD PLOTTED ON LOGARITHMIC COORDINATES

atmosphere. Only a small amount of air is passing to the engine. Under these conditions the relative vaporization rate will be substantially at its maximum, since the pumping strokes of the engine withdraw the vapor from the liquid surface as fast as it is formed, and maintain a low total pressure of which the vapor-pressure is only a part. The result is that relatively little liquid exists in the manifold, and its walls are as nearly dry as they ever can be.

Now let us open the throttle somewhat. The immediate results are rise of pressure and the passage of more air and more fuel. From a vaporization standpoint, the circumstances are: (*a*) increased density of the fuel vapor at the liquid surface; (*b*) reduced relative surface exposure of the liquid; and (*c*) lowered intake temperature. Each of these items is a powerful deterrent to vaporization; and the net result of opening the throttle is that the relative vapor-content of the charge, upon which we depend for regular ignition and good performance, will be much reduced until such time as the intake walls have become more extensively wetted, increasing the exposed surface of the liquid fuel and thereby partially restoring the vaporization rate. In the conventional intake system, the throttle-valve is interposed between the intake-manifold and the sprayer or nozzle of the carbureter. As the fuel passes the nearly closed throttle it is subjected to extensive spraying, and therefore to extension of its surface, which spraying is by no means equalled by that at the ordinary nozzle under any condition of operation. Attention is directed to Fig. 4 which gives a very good idea of what happens at the throttle of a carbureter at its several positions. This photograph was published in my paper on Intake Flow in Manifolds and Cylinders.[3] Attention is called to the marked differences in agitation and churning-up of the fuel as the throttle position is changed.

If the throttle is now closed to bring us again within the speed limit we accomplish: (*a*) reduction of density of vapor at the liquid surface; (*b*) extension of the exposed liquid surface; and (*c*) rise of intake temperature. Each of these is a powerful accelerator of vaporization; and, opposed to them, the heavy accumulation of liquid on the manifold walls does not stay there very long, but goes into the cylinders and causes excessive enrichment.

VAPORIZATION IN THE CYLINDERS

The question as to what fraction of the fuel supply can enter the cylinders as liquid and still be completely burned is almost impossible to answer. No doubt the size of the admissible unvaporized fraction varies chiefly with the fuel, but it varies also with the extent of its mechanical division, with the temperatures of the walls it falls upon, with the temperatures to which it is raised and with the pressures to which it is subjected during compression and the early part of the combustion.

The term polymerization is defined as the act or process of changing one substance into another which has the same composition but a different molecular weight. The polymerization products of petroleum compounds attain extraordinary molecular weights; the very heavy compounds are resinous and tarry, and their combustion is almost impossible. The increased rate of carbon-deposit formation that has been generally experienced during the past year is usually explained on the ground of high polymerization of our later fuels.

If the fuel is one that does not break-down, and does not polymerize, it is entirely possible that the liquid surviving the compression will vaporize or may attain its critical temperature during the combustion; and will then burn rather well along in the expansion stroke, appearing on the card as a sustained combustion, or even an after-burn. Most cards from automobile engines, when plotted on logarithmic pressure-volume coordinates, show an appreciable length of the early expansion-line to have a slope close to unity, as in Fig. 5. This can mean only that the combustion is continuing at a rate sufficient to maintain the temperature of the gases at a nearly constant value, in spite of the expansion.

Fig. 5 shows a typical part-throttle indicator-card plotted on logarithmic coordinates. The data from which this plotting was made were obtained at the Bureau of Standards, with the point-to-point diaphragm-type indicator developed at the Bureau under the direction of Dr. H. C. Dickinson. The graph gives a good idea of the closeness of the work that can be done with this form of indicator. In such a plot as this one, the exponent in the expression for adiabatic compression or expansion is scaled off directly. Note the change in slope of the expansion line, to which attention was directed previously. Also note the small value of the exponent n for the compression stroke. If there were no heat losses from the compressing gases, this n would have a value of 1.41. But, of course, there are heat losses, and the major one is, no doubt, the heat loss to the fuel that is being vaporized during this part of the cycle.

[3] See THE JOURNAL, March 1921, p. 282.

With our present fuels, it is well to depend as little as possible upon the cylinder heat and temperatures to complete the vaporization of the fuel. Most of our fuels break-down too easily, and many of them polymerize extensively. Both these things cause rapid fouling of the combustion spaces, and particularly of the intake-valve heads, since the latter are thoroughly wetted by unvaporized fuel.

A further argument is that the greater the dependence upon vaporization in the cylinders, the greater will be the liquid mass in the intake-manifold to be distributed among the cylinders and, obviously, the more difficult it will be to secure its equal distribution. Small errors in the distribution of the liquid in the manifold represent very gross ones in mixture proportions within the cylinders. But, no matter how much liquid fuel we may be willing to have in the intake passages and cylinders, there always must be sufficient vapor in the charge at the time of ignition to support combustion, or the engine will not operate. Bearing in mind the valuable effects of (*a*) extension of liquid surface; (*b*) rise of liquid temperature; and (*c*) reduction of vapor-density at the liquid surface, and having considered the conditions in the intake passages, it is interesting and useful to examine the interior of the cylinder.

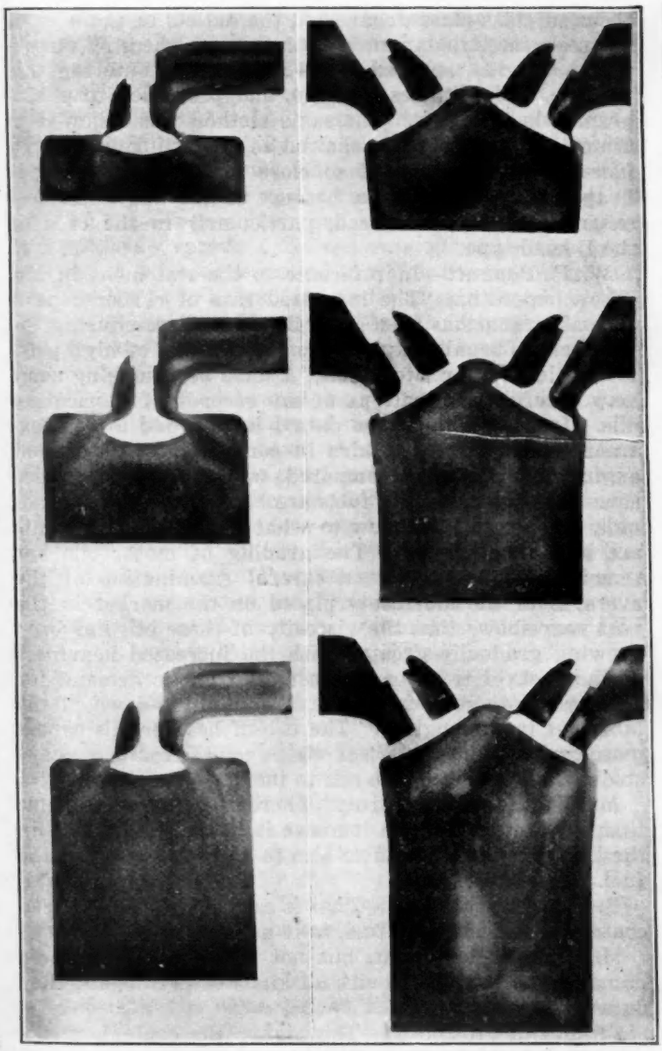

FIG. 6—INTAKE FLOW IN TWO TYPICAL VALVE-IN-THE-HEAD CYLINDERS

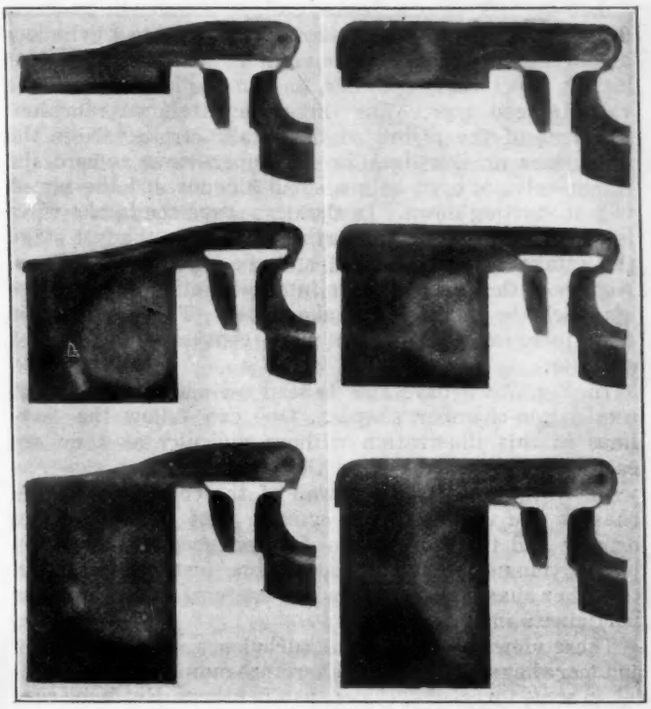

FIG. 7—INTAKE FLOW IN TWO FORMS OF L-HEAD COMBUSTION SPACE

In the intake, the fuel is sprayed at the carbureter nozzle, churned-up at the throttle and spread over the passage walls to increase its surface. This increases not only the area from which vapor can emanate but also the area through which heat can pass to the liquid to maintain or raise its temperature. Furthermore, at the same time the fuel is being spread out, as it were, its vapor is being swept away from it, accelerating its vaporization and increasing its ability to absorb heat by lowering its temperature.

Referring again to Fig. 4, the throttle is here taken through a complete cycle of 180 deg. Notice the differences in agitation, churning-up and, therefore, extension of liquid surface among these several throttle positions. It is perfectly obvious that the greatest spraying effect is obtained with the least throttle-opening.

By the time the liquid that is left gets into the cylinders, the density of the vapor in contact with it is greater than was the case in the intake passage. The sources of heat supply with which it now comes into contact are greater and may have higher temperatures than those of the intake. For this reason, vaporization may progress right up to and even after ignition. No doubt it does so under some conditions of operation, no matter what the fuel; and perhaps it does so under all conditions of operation with some fuels. However that may be, if the characteristics of the fuel and the temperature gradients and the pressures that exist permit further vaporization, the only way to carry it forward at the highest possible rate is to extend the liquid surface, just as in the intake. The greatest effect of this sort must follow the highest possible rate of homogeneous and therefore orderly internal motion of the charge. This motion is described as orderly turbulence. That the turbulence in the intake may be reasonably orderly and at the same time high, is clear.

Let us look into a few cylinders, as shown in Figs. 6 and 7. In Fig. 6, we have two valve-in-head cylinders of different design. On the right is something approximating the Liberty cylinder, and on the left an ordinary valve-in-head type. The three stages shown represent positions of the piston on the intake stroke. Note the turbulence or flow-lines in the upper views, where the intake-valve is open only a small amount and the piston is just starting down. In the next stage the intake-valve is wider open, the piston farther down. In the last stage the intake is nearly closed and the piston clear down. Note how the turbulence or internal motion fades as we approach the end of the intake stroke. This condition is even more marked in the more conventional form of cylinder.

In Fig. 7 we have two L-head cylinders of different combustion-chamber shapes. One can follow the flow-lines in this illustration without difficulty as they are easily distinguished. Note that the change in slope, as we may call it, of the top wall of the combustion space changes the volume of the cylinder that is swept by an orderly and therefore useful internal motion. The turbulent volume is flattened out in one instance but, with the other shape, nearly the whole contents of the cylinder participate in the motion.

These views show that the turbulence is more orderly and more homogeneous, and therefore more active and useful, in some forms of cylinder than in others. But in no case does the cylinder turbulence approach that of the intake. High cylinder-turbulence is a desirable thing and should be realized to the utmost in all engines; but, because of the limitations imposed upon its usefulness by fuel characteristics and by the values and distributions of the cylinder temperatures, it cannot be greatly or consistently relied upon to build up a usable vapor-content in the charge.

THE DISCUSSION

CHAIRMAN H. L. HORNING:—Will Mr. Tice repeat the partial-pressure demonstration with the barometer tube?

P. S. TICE:—The demonstration is made with a tube having within it an unoccupied space; that is, it is a normal barometer. The introduction of a liquid into the tube fills the space with vapor and, because of the temperature at which the liquid exists, the vapor has a certain pressure, which is represented by a fall in a mercury column. This fall is read and noted. When the contents have been expelled and the tube sealed, the vapor-pressure tube becomes a barometer also. By keeping the leveling bulb down and using the apparatus as a barometer, air is admitted which raises the pressure. The change in the height of the mercury column represents the increase of pressure in the tube, due to the air. Pouring some of the same liquid used in the barometer tube into the vapor-pressure tube by means of a funnel and then readjusting the leveling bulb so that the air and the vapor together occupy the same volume that the air alone occupied before the introduction of the liquid, it is found that the change in pressure due to the vapor is the same both in the barometer tube having no air and in the vapor-pressure tube having air.

CHAIRMAN HORNING:—If another liquid were introduced, there would be a still greater drop; and the introduction of still another liquid would cause another drop. The fundamental lesson in this is that there are the same number of molecules in 1 cu. in. of any gas at the same temperature and pressure. That is a very important law. If we continue to introduce more liquid, the pressure continues to rise because the pressure is controlled by the number of molecular bombardments there are in a unit of time, and pressure refers to how fast the molecules are going. In this demonstration, as soon as heat was introduced the velocity began to increase, and the heat absorption appeared in the velocity of the particles, which were thrown into a vapor state. When they cooled down, what the cooling down meant was that they had come into touch with something that was moving rather slowly and that this had taken the velocity out of them. But the slow-moving object also gained a little velocity, and finally it had as much velocity as the particles. The liquid state and the gaseous state were then practically the same.

FREDERICK PURDY:—How were the photographs taken of the phenomena inside the cylinder and the manifold?

MR. TICE:—Before undertaking the work, we decided that the flow in both halves of a symmetrical passage, such as the intake passage, would be symmetrical when the halves were divided by a plane; and that we could put such a plane through the passage without destroying the flow-lines. In other words, flows coming through the back of the passage normal to a glass plate would be met by equal flows from the other half of the passage. We split some intake pipes down the middle and cemented them on glass plates, connected the outlets of those pipes to an engine intake, pumped air through them by motoring the engine, sprayed liquid into the air entering this passage, had throttles in place, and proceeded to photograph what we saw. The same method was followed in the cylinders. What we showed as happening in the cylinders was probably not so close to the truth as it is in the case of the intake, because of the unsymmetrical shape of the cylinder-head, particularly in the case of the L-head type.

W. F. PARISH:—In reference to the statement in Mr. Tice's paper that "The increased rate of carbon-deposit formation that has been generally experienced during the past year is usually explained on the ground of high polymerization of our later fuels," I have been making some very careful examinations of my records of lubricating oils. In assembling these data I have found a most extraordinary state of affairs in connection with present engine lubricants as compared with the same grades some years ago. Liquid fuels are becoming heavier gradually but we do not know to what extent the lubricants are becoming heavier. The grading of motor oils has remained the same, but a careful examination of the averages of the lubricants placed on the market in the past year shows that the viscosity of these oils has been growing gradually greater with the increased heaviness of the fuel. I refer to the increased public demand for heavier oils to compensate for the thinning-down of the lubricant in the engines. The use of heavier oils causes more carbon, a large part of which comes from the heavy stocks that are put in the oils to increase the viscosity.

MR. TICE:—That is true. There is evidence to show that a large part of the increase in carbon formation in the last year is attributable also to polymerization of the fuel.

CHAIRMAN HORNING:—That is caused by the increased content of unsaturated fuel, is it not?

MR. TICE:—Somewhat, but not entirely. The things do not go hand-in-hand with all kinds of petroleum; they do with some.

CHAIRMAN HORNING:—The higher the content of unsaturated fuel, the greater the polymerization is apt to be. The unsaturated fuels are the ones that have the two extra hydrogen atoms left out. Some are called

olefins, but as they become heavier, they have a tendency to break in two and make a more complicated substance. They do just the opposite to cracking; the cracking breaks-down into the simpler system and the polymerization steps-up into the more complicated. Anyone who has had an engine with the intake opening before dead center will know what I mean. In such an engine the hot gases are pushed back into the intake passages and the valve will coat-up rapidly with a gummy substance, like varnish. We had an engine go wrong in that way and we found that the timing was wrong, although I tried to prove that the fuel was wrong. The deposit on an intake-valve is due to polymerization. In order to find what causes polymerization, we tested many unsaturated fuels in the laboratory and found both moisture and oxygen to be necessary. We found that an almost imperceptible amount of moisture would start the trouble; but there was no trouble when the fuel was absolutely free from moisture or any oxygen-bearing material.

MR. TICE: — This critical-temperature phenomenon is something with which most of us are unfamiliar; it should be observed in detail.

B. STOCKFLETH:—What is the time element for vaporization in the manifold?

MR. TICE:—The time available for vaporization in the intake is only the time that is required for the liquid to travel from the carbureter nozzle into the intake. It depends upon the velocity of the fluids in the intake and the length of the intake.

MR. STOCKFLETH:—If a certain amount of kerosene is put into the manifold by the carbureter nozzle, and if there is a heated chamber into which it will pass, it will take a certain time before the fuel will become a dry gas?

MR. TICE:—Yes. The time required for that to be accomplished depends upon the rate at which the temperature is raised, the extent to which the fuel is spread out, the area of the surface and the rate at which the vapor is taken away from the liquid. The more useful way to consider the rise of temperature of the liquid is to look at it from the point of view of the rate at which we put heat into it, although the controlling factor is actually the temperature of the liquid.

MR. STOCKFLETH:—In an experiment I am making at present, instead of using the ordinary carbureter-nozzle that creates a fog in the manifold, I poured the kerosene through a fixed orifice into various channels or troughs and let it vaporize only as the heat came to it from the exhaust gases surrounding these pockets. In that way I was able to get a very much clearer mixture than I did by having it pass through the carbureter. This was evident when looking through a peep-hole.

MR. TICE:—Yes, there would be a dry mixture under those conditions. We would all like to do it that way, but can you do that at a useful rate?

MR. STOCKFLETH:—I kept the fuel at a constant flow. I was not attempting any great degree of flexibility, but was surprised by the flexibility shown.

MR. TICE:—I mean, could you run an engine by this method and accelerate it? Could you do the necessary things?

MR. STOCKFLETH: — The proposition is only experimental. It shows that the carbureter action is not needed except for flexibility.

MR. TICE:—Exactly. You accomplished the result by doing exactly the same things as in a conventional arrangement, but gave them a little different order of prominence. You cut out practically the extension of surface and did it entirely by sweeping away the vapor and by heating the liquid. Of course, the rate at which you evaporated the fuel was much lower and the weight of fuel evaporated per unit of time was much less than if you had sprayed the fuel.

J. W. STACK:—Has Mr. Tice determined within a reasonable range what vapor-tension is necessary in a fuel in order to have sufficient vapor to turn over an engine at zero atmospheric temperature?

MR. TICE:—I have never attempted to measure that. I do not see what good it would do us to know it. We are limited to certain sets of conditions.

MR. STACK:—In other words, gasoline can be made with a certain percentage of hydrocarbons boiling over below a certain temperature. What is the maximum or the minimum percentage of those light boiling-points necessary to produce combustion to heat the engine at a low temperature?

MR. TICE:—I do not know. I have never attempted to determine that. So long as the fuel has components that will flash at our starting temperatures, we can start by choking enough fuel into the engine. In his booklet[4] on Economic Utilization of Fuel, Prof. C. A. Norman has computed the mixture temperatures at which we can support as vapor the necessary fuel to burn, for fuels of different mixtures.

As stated in his paper on the Condensation Temperatures of Gasoline and Kerosene-Air Mixtures,[5] Prof. R. E. Wilson has made experiments and obtained some data on the temperatures at which different ratios of fuel mixtures can exist and still have all the different fuels in the vapor state. These data are all interesting and useful but they do not tell us how to arrive at that condition. They tell us how low the temperature may go and the fuel still be in condition to burn, but they do not tell us how to reach that condition within the time available. The rate of vaporization is our limiting factor. Professor Wilson emphasizes this point. What we need is a higher rate of vaporization. Professor Norman discusses the desirable height of mixture temperatures, the results of using higher temperatures, the losses to be sustained and the like. If we could devise some compact apparatus that would evolve vapor at a rate to permit us to form the charge and keep it dry, we could work at the temperatures computed or determined experimentally; but, because we cannot usually do that in practice, we necessarily must work at a higher temperature. The interchange of heat ordinarily is not complete by the time we have to burn the liquid. Mr. Stockfleth's experiment is right in that respect. He obtained a drier charge by allowing more time. He took much longer to evaporate the liquid. If we apply such an apparatus as that to an engine, it must be an apparatus involving a considerable time-interval.

MR. STOCKFLETH: — In regard to Professor Wilson's and Professor Norman's determinations of the condensation points of kerosene and of ordinary gasoline, as shown by tests performed recently, I find, by looking through the peep-hole, that even at a temperature of about 110 deg. fahr. above the condensation temperature as given by Professor Wilson, a slight fog is indicated in the manifold. The temperature Professor Wilson gives is the condensation-point for a dry mixture of kerosene as about 220 to 230 deg. fahr. The maximum mixture temperature in my experiment was 195 deg. fahr. and showed a large quantity of fog. How much more heat would be needed to obtain a temperature as high as 110 deg. fahr. or more above the vaporization point as was the case of the 440-deg. end-point gasoline

[4] See Ohio State University Bulletin No. 19.
[5] See THE JOURNAL, November 1921, pp. 313, 314 and 318.

to produce a dry mixture? Would it be necessary to go very much higher for kerosene, to get it above the condensation-point?

MR. TICE:—The vapor temperatures would need to be higher than those given by Professor Wilson or Professor Norman to form a dry charge. Suppose we put liquid fuel in one end of a chamber and draw nothing but vapor from the other end. In its passage through the chamber the fuel is completely vaporized. The vapor outlet is in communication with an air passage. The vapor is saturated; we are vaporizing in a chamber where there is no air. In other words, the vapor-pressure is the whole pressure within it, and the temperature of the liquid must be high enough to support that pressure. When we allow this vapor to pass out and mix with the air, its initial admixture is very incomplete and non-homogeneous. We will get a partial condensation, a liberation of heat, a rise in temperature of the air and a foggy charge; after that we will need to make a further application of heat to dry the charge again because of the imperfections in our means for transferring heat from one substance to the other, or to the liquid particles.

CHAIRMAN HORNING:—Some of the constituents are bound to gather in the form of globules as they go along. As Mr. Tice pointed out, we can burn these globules very efficiently provided they do not become too large. It is difficult to determine just what size is permissible. To obtain a perfectly clear, dry mixture, would require exceedingly high temperatures. Dr. H. C. Dickinson covered that point in his test of the Chalmers engine at the Bureau of Standards, in checking the fuel report that the Society published concerning hot-spots. He observed the temperatures up to 500 deg. fahr. and had liquids running through the manifold even when using a gasoline such as Red Crown. There were some particles that would not stay in the form of vapor at 500 deg. fahr. We would like to have the mixture dry, but there is a point beyond which we do not like to go. I carried on a series of economy tests on one of Mr. Stockfleth's engines for an entire week, to illustrate that. The intake-manifold was entirely surrounded by the exhaust-manifold. The exhaust-manifold was red-hot on the outside; therefore, we had the highest temperature possible.

When Mr. Stockfleth's engine was giving slightly more than 0.570 lb. per b. hp-hr. on gasoline, it would show 0.591 lb. per b. hp-hr. on kerosene. The difference was almost insignificant. During the week's tests the difference in thermal efficiency between gasoline and kerosene was consistently 0.021 lb. per b. hp-hr. The temperatures were high enough to vaporize all the fuel, or at least to get it into such shape that it would do the work. The difference was due merely to some difference in volumetric efficiency, referred to by Mr. Tice. On account of the temperature changes and the vaporization, we got more in with the gasoline than we did with the kerosene; therefore, we obtained a higher thermal efficiency.

MR. TICE:—With the same specific consumption per horsepower-hour, the thermal efficiency is less for kerosene than for gasoline?

CHAIRMAN HORNING:—Kerosene has a higher heat-content than gasoline, and yet we do not get the returns. That is a very important distinction.

MR. TICE:—There is one range of conditions in which we do get an equal or higher thermal efficiency or, in other words, a much less specific fuel-consumption of kerosene than of gasoline; that is, from about one-half load down to the minimum load. It is common to find differences in specific consumption in favor of kerosene of some 6 to 8 per cent.

H. C. GIBSON:—A development in connection with the Knight engine is pertinent to the present discussion. I have contended for many years that we can get more out of fuel by attention to what can be called the alimentary canal of an engine. Engines do not assimilate all the present-day fuel that is fed to them, principally because they do not masticate it for a sufficiently long period.

The inherent rate of vaporization of the fuel is the controlling factor. It has been my belief, and this is now confirmed, that we can evaporate the fuels to a usable condition without introducing liquid fuels into the cylinder. I entirely disagree with any belief in our ability to burn liquid fuel economically, completely or satisfactorily within the cylinder of an automotive engine. I designed and built a car with a 133-in. wheelbase, weighing approximately 5400 lb. loaded, having a rear-axle ratio of 3 10/13 to 1 and a six-cylinder engine of 3¾-in. bore and 6-in. stroke, or 397-cu. in. capacity. It showed remarkable flexibility without changing gears from 2 to 75 m.p.h., without any missing or choking. The fuel consumption on a concrete road at 25 m.p.h. was 1 gal. per 51.4 ton-miles, which is approximately 18.6 miles per gal. According to all the rules, I think an engine of such size in such a car should have shown something less than 12 miles per gal. under ordinary conditions. The crankcase-oil dilution, after 3000 miles of operation without having drained the crankcase, was 8.8 per cent of comparatively heavy distillate, none of which distilled over at less than 410 deg. fahr., the final temperature of the test being 570 deg. fahr. The distillation operation lasted for 90 min., which was time enough to give every opportunity for distilling every drop, including whatever was cracked out of the lubricating oil. It was shown that a very small proportion of true gasoline was in the crankcase oil. Such gasoline as was there comprised only the heaviest ends, and I am rather inclined to doubt that there was any gasoline there at all. Distillation tests run at the standard rate showed no gasoline whatever. The carbon deposit after 3000 miles was really negligible; it could not be measured and could be wiped off. It seemed to have reached a point where it just coated the surfaces, and it did not increase after that first coating had been put on.

The wear of frictional surfaces was not measurable, and there was not a noticeable pound, detonation, or any other disagreeable noise in the engine of any kind under any conditions. In fact, we could not make the engine "ping," although the compression pressure was 88 lb. per sq. in. gage, by three different methods of test, or a total of 103 lb. per sq. in. absolute. It was specifically timed for slow-speed operation, not to exceed in ordinary use 1500 or 1600 r.p.m. All the conditions of that engine are utterly wrong according to general practice, but since they worked out so extraordinarily well they must be worth noting.

This was all attributable to the particular attention paid to and treatment of the alimentary canal of the engine, so to speak. It started at the entrance of the air to the hot oven, which delivered air at a considerable temperature to the carbureter; and such metered mixture of air, gas vapor and liquid as came from the carbureter was inspired into a manifold in which no attempt whatever had been made to maintain the velocity of the gases. In fact, it was just the opposite; the manifold passages were of much greater area than the carbureter-flange passage. It was a plain manifold running straight to each of the cylinders, with a little obstruction to each of the nearer cylinders; that is, more obstruction to cylinders Nos. 3 and 4 than to cylinders Nos. 2 and 5; and a little more obstruction to cylinders Nos. 2 and 5 than to

cylinders Nos. 1 and 6. But the main feature of that manifold was very similar to the one mentioned by Mr. Horning, in which the whole of the manifold was jacketed by exhaust gases. The intention was to get as much area as possible available for the evaporation of the liquids, and special attention was paid to and provision made for the catching or trapping of the liquid particles that would be in the manifold under all conditions with the present fuel, and the cooking of those liquid particles off into a gas. That was accomplished by the use of long ribs in the upper and lower halves of the manifold. The manifold was split throughout the length so as to get a perfectly clean job. The ribs, acting like the banks and the bottom of a river and retarding the movement of the gases through the manifold, had the effect of giving a somewhat circulatory motion to the gases traveling along the lower half and, similarly, to those traveling along the upper half. By centrifugal force, that motion threw out some of the liquids that were in suspension in the airstream, so that they were deposited on the rough surfaces of the ribs and were cooked off.

The temperatures of the mixtures going into the cylinders were comparatively low, say 150 to 180 deg. fahr. We could run that engine on any one cylinder after getting it warmed-up, and, so far as we could judge with good test apparatus, we could get practically the same results with any cylinder working with all the others cut out. That showed pretty good distribution.

F. G. SHOEMAKER:—In manifolds in which an attempt is made to supply the heat of vaporization at a very high rate, assuming that heat can be supplied at a very high rate, is there any chance that the fuel will crack if it is in the presence of all the air that is traveling with sufficient velocity to blow it over the liquid fuel?

MR. TICE:—I will not say that it is cracking or what it is, but we do get a deposit in the intake passages. It never amounts to much in thickness; it is rarely found to be more than 0.001 in. thick. One cannot chip enough of it off to measure its thickness accurately, but we do get a deposit which, so far as we can distinguish, is identical with the accumulation at and around the intake-valve.

MR. SHOEMAKER:—In an intake passage that was ribbed in such a manner that an appreciable depth of liquid fuel was caught and held so that air in passing through the intake would not sweep the vapors off and the liquid fuel would boil, would one be more likely to have cracking?

MR. TICE:—Yes, if the intake were arranged to trap liquid, as Mr. Gibson has suggested. Let us consider what happens when we open and close the throttle? We have these extensive accumulations in the intake pipe and any subsequent reduction of pressure in it will cause a higher rate of evolution of vapor from them. The accumulation of liquid will be at its maximum under open-throttle conditions.

When conditions controlling vaporization in such an intake are at their best, we get an excessively rich mixture. Correspondingly, if we provide these pockets, the mixture will be impoverished during the time the pockets are filling. We are taking liquid out of the mixture and, while going from a small throttle-opening to a large one, we will impoverish the mixture in the cylinders. Then, when we close the throttle, we take the liquid out of the pockets.

MR. SHOEMAKER:—Tests were conducted in connection with that point, at Ottawa Beach, in 1920. The conclusion was reached in the report[6] that the rate of acceleration was increased by increasing the intake temperature. It seemed that the obvious point was overlooked, that the improved acceleration was not due to the increased temperature of the intake gases, but to the smaller amount of liquid fuel in the manifold.

MR. TICE:—Upon opening the throttle, the vaporization rate is spoiled as would be the case if much more liquid were in there but, relatively, it is not spoiled so much.

CHAIRMAN HORNING:—Acceleration is the function of the energy content in the mixture at the moment the spark jumps. Therefore, the more fuel in the form of a vapor at the moment the spark jumps, the greater is the energy released. If a large part of the fuel is in liquid form, it will not be released. Dr. Dickinson's demonstration was beautifully illustrative of this point.

MR. TICE:—Fuel in the liquid state does not burn and that is all there is to it.

MR. SHOEMAKER:—In testing out an oil-pressure regulator, I connected a milk bottle as a trap on the vacuum line to the manifold and noticed that the vapor apparently was rushing back-and-forth into the milk bottle from the manifold. I could not believe that it was coming through a length of ¼-in. tubing, and came to the conclusion that the action was due to the pulsation in the manifold, which caused the vapor in the bottle to pass through the dew-point. I believe we see some of the same effect in a manifold when we put in glass windows, and that the momentary waves of high pressure passing back-and-forth through the manifold make us think it is fog, whereas it may be a dry mixture. I have had that occur in manifolds that were bone-dry on the walls, and could not get rid of the apparent fog.

MR. TICE:—Regardless of what the throttle position is or what the load on the engine is, there is a pulsation pressure in the intake pipe. With the ordinary four-cylinder engine this pressure will run to about 70 mm. (2.756 in.) of mercury. In a four-cylinder engine it varies by about that amount twice per revolution. The change of the total pressure in the intake represents a corresponding change in vapor-pressure. We get exactly what we must expect, in condensation and re-evaporation of the fuel, every time that pressure changes. This is most clearly to be observed when the engine is running at a low speed. If we have a milk bottle or any chamber on the intake, the pulsation in pressure gradually pumps vapor into the bottle and pumps air out until, finally, we have substantially the same mixture in the bottle as in the intake pipe. A small hole merely delays the action. A larger passage allows it to happen earlier. The pressure is changing twice per revolution in that bottle.

W. H. HOLLISTER:—Mr. Tice showed the different openings of the conventional type of throttle and the turbulence in the manifold. Did he ever experiment with a throttle of a different type that would open from the center with a gradually enlarging aperture? If so, what effect would that have on the turbulence and the wet manifold?

MR. TICE:—That has been done. With a conventional butterfly throttle valve, standing at an angle and being partially open, the greater part of the flow gets past the downstream edge. There is an eddy space behind the throttle where the fluid is revolving. The liquid content of that eddy in an intake will increase to a certain amount but will not become any greater. Liquid is passing into and out of the eddy. With this throttle-valve, except for the content of the eddy, the whole of the passage is being swept by the air.

[6] See THE JOURNAL, September 1920, p. 228.

Suppose we have a throttle that opens up like the iris diaphragm of a camera. The mixture is flowing upward, and we get a symmetrical ring, or doughnut-shaped eddy above the iris. The liquid content of the eddy is relatively greater and the shape does not permit the eddy to elongate; in other words, the eddy remains circular in section, which is the most favorable shape for retaining the maximum amount of liquid. In the butterfly throttle, the eddy includes only a very narrow sectional area and the liquid content of the eddy is less.

In the intake-manifolds I have shown, when the throttle-opening, corresponding to an almost closed iris throttle, was very small and we got a short distance above the throttle plate, the whole cross-sectional area of the pipe was working; but that would not be the case with the iris throttle. We would have then an excessive wall accumulation of liquid and minor eddies clear up the wall until the stream expanded to sweep the walls again.

CHAIRMAN HORNING:—To obtain a distillation diagram, the fuel is put into an Engler flask to which a flame is applied. The temperature of the vapor will assume a definite value which we plot. The curve representing the percentages coming off is known as the distillation curve, which is used generally by the oil industry. If we take Mr. Tice's kerosene and mix it with the very fine unknown substance that he used, some of the heavy particles will come off first; in other words, it does not separate in a well defined way. There is an appreciable quantity of this very heavy end-point in the first distillate that comes off at what is called the initial point. Likewise, when we come to the end-point, we have not yet succeeded in distilling off all this light stuff, although we have been fairly successful. There are some things coming off at the time which we call the end-point, when the material is almost dry. Since temperatures and percentages are involved, a distillation curve is a methematical expression of a large number of complicated physical factors.

The interesting thing that Professor Wilson has shown is that the temperature of condensation of a 12-to-1 mixture is very important. It proves that the temperature at which Red Crown gasoline will start to condense from a 12-to-1 mixture, which is a rather rich mixture, is far below the point at which the first part of the gasoline comes off in distillation. The standard specification calls for an initial temperature of 140-deg. fahr.; therefore the initial point of condensation is about 20 deg. under the initial boiling-point. This statement holds true for all fuels except those made in Oklahoma from very heavy stuff, and from some of the very light stuff when it is possible to get the condensation point above the initial-point.

If we start a liquid to boiling in an Engler flask, we keep taking off and replacing just the amount that comes off; in other words, what comes off first is mostly the lighter ends, but we are always dragging off some of the heavier ends. Finally, we come to the point where there is no change in temperature; in other words, what is coming off and the liquid in the bowl have the same composition. Consider the drops that rush through a manifold at the rate of 150 per sec., as they often do. The outside layers give off their lighter constituents and finally, as the globules get along far enough, the vapor coming off is the same composition as that of the liquid left on the walls.

To show what distillation means and what the end-point means, suppose we take some of this liquid that has the same composition as the stuff coming off, and distill it. We shall find that it is not this heavy fuel at 30 deg.; that it has an initial-point considerably above this, and that the distillation curve runs parallel and ends 40 deg. higher than the end-point of the fuel. This shows that the end-point of the original distillation was merely a mixture with some lighter fuels. That is very important. When we have talked about end-point, we have thought that we were talking about the heaviest constituents in the fuel. The heaviest fuel is there in large quantities, but not exclusively. The curves of the original fuel and the distillation curves of the equilibrium mixture, all run about parallel.

Professor Wilson has worked out a rule by which, if we take the temperature of the 85-per cent point of the fuel and subtract a constant number of degrees, we get a point at which we have ideal condensation of a 12-to-1 mixture. This is a rough rule and a fairly good one; 243 deg. fahr. from the 85-per cent point would give the distillation point.

That is a very important advance in our information, and it is only because our apparatus is imperfect that we must carry temperatures higher than those of the condensation-points. It, therefore, behooves us to make the very best and most skilful use of surface and of temperature distribution, along the line that Mr. Tice has pointed out, in order to keep these temperatures low; because, it is these temperatures that determine volumetric efficiency, the volumetric efficiency determines the weight of air, the weight of air determines the amount of oxygen, and the amount of oxygen determines the amount of fuel that will burn completely. Therefore, the temperature is a very important thing. The weight of air is one of six or eight factors, but it is the most important factor in determining the horsepower that can be developed in an engine.

MR. TICE:—The weight of air determines the power, other things being equal.

CHAIRMAN HORNING:—Another important thing is that, when the mixture is lean, the amount of energy available depends entirely on the amount of fuel. The moment that one gets the correct proportion, the problem changes. When there is not enough air to neutralize the fuel, we have fuel left over. With the fuel left over, if we go just a reasonable distance beyond, the power will still go up, due to the volume of gas in the cylinder, although the excess liquid does not enter into useful combustion.

MR. TICE:—If we have an engine running on a lean mixture and we progressively enrich the mixture, we progressively increase the power until we arrive at a certain point where any further enrichment of the mixture actually increases the amount of air taken into the engine. The brake mean effective pressure curve plotted against the mixture-ratio starts up; by continually enriching the mixture, the curve becomes flat, then goes up, then becomes flat again. Finally, if enrichment be continued, we reach a point where the temperature is not reduced further and the amount of air taken in is not increased.

The relative importance of the conditions discussed as controlling vaporization, as they exist and can be made to exist in the intake system, is best understood if we think in terms of the rate of vaporization. This latter quantity is solely dependent upon the rate at which vapor is removed from the liquid surface and the rate at which heat is imparted to the liquid. Assuming a given degree of turbulence, or internal motion in the gas and vapor-content of the intake, and a given total pressure, the rate of removal of vapor from the liquid surface is relatively a fixed quantity, except as it varies with the rate

of vapor evolution from the liquid. Since this is the case, the general statement can be made that the control of the vaporization rate in the intake is entirely a problem of the ratio of heat input to the quantity of liquid fuel.

Professor Wilson's paper[7] gives a complete and concise statement of the possible conditions of the charge that accompany given intake temperatures. It is based on experimental evidence and is applicable to several typical fuels. But note particularly and do not forget the following comments:

> It must be emphasized at the outset that results secured by such methods represent conditions prevailing at equilibrium. It is possible to obtain "wet" mixtures at temperatures well above the dew-point, because the drops of fuel that are sprayed into the airstream do not have sufficient time to absorb heat and vaporize before the mixture reaches the engine. The results simply indicate what is theoretically obtainable if the time, the degree of atomization, etc., are sufficient to permit equilibrium to be approached fairly closely
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> These results indicate clearly that any difficulties in securing complete vaporization of the present commercial gasoline are not due to any inherent limitation in the gasoline itself, or to too low manifold temperatures, once the engine is warmed-up. Indeed, where any serious attempt has been made to heat the incoming gases or the intake-manifold, the temperature attained by the airstream is almost invariably far higher than theoretically necessary. Improvement in vaporization apparently should be secured by better atomization, longer times of contact or by throwing the unvaporized particles out of the insulating airstream onto a hot-spot, rather than by raising the temperature of the mixture as a whole with the attendant disadvantages of this

The obvious means of accelerating the vaporization rate is an augmented heat-input following the extension of the liquid surface and an increase of the temperature gradient across that surface. Let us first consider how we can extend the liquid surface. Since, ordinarily, the entire wall of the intake passage is well wetted in any case, there is no opportunity to go farther in this direction without building longer passages or putting alcoves on those we have. Then, too, the extension of surface accomplished by this means could be only relatively small and wholly inadequate.

The feasible alternative then in this direction is extension of the liquid surface by finer division or spraying of the fuel. Considering that the sprayed fuel assumes a globular or spherical form, with any reasonable degree of division, it is useful to examine the relations between surface and mass for different possible dimensions of globules, since, other things being equal, this is the relation that determines the rate at which heat can be taken on. The surface of a sphere is equal to πd^2. Its volume, and therefore its relative mass for any single liquid, is equal to $\pi d^3/6$. The surface is as the square and the volume as the cube of the diameter. Setting surface over volume, the relation or ratio $S/V = 6/d$ is found, which shows that the surface-to-volume ratio is inversely as the diameter. To make the case concrete, let us say that one sprayer divides the liquid into globules having a diameter of 0.030 in., just under 1/32 in., and that another sprayer discharges the same amount of liquid but in globules of 0.002-in. diameter. Both of these diameters are entirely reasonable. The smaller globules are 1/15 the diameter of the larger, the surface exposure of the same mass of liquid is 15 times as great in the smaller globules and, if the temperature gradient across the surfaces is the same, the smaller globules will *begin* to vaporize at 15 times the rate of the larger. But as vaporization goes on in these two cases with a fixed temperature-gradient, the difference in rate mounts up enormously and will be thousands of times greater for the smaller globules at the time when their last bits change to the vapor state. But there are very serious difficulties in the way of realizing the foregoing. The smaller the globules diffused through the airstream are, the greater the thermal influence of a globule will be upon its neighbors, the more perfectly they will follow the internal motions in the airstream, and the greater the difficulty is in maintaining a fixed or suitable temperature-gradient from a source of heat supply.

If the object sought is a dry or completely vaporized charge, formed in the least possible time, it is necessary largely to prevent diffusion of these small globules into the airstream, and to remove them from the heat-insulating airstream to a place where heat can be taken on nearly equally by each of them, subsequently returning only their vapors to the airstream. The need to separate the globules from the air and to apply heat to them alone follows from the fact that we desire the minimum total heat to be given to the charge. Obviously, if the source of heat supply is accessible to the airstream, the latter will take on heat that will be of little or no use in forwarding vaporization, and will appear as a needlessly high temperature of the charge.

When the fuel is thus separated from the airstream, which it must accompany originally for the sake of metering in the carbureter, the need for a fine division of the liquid increases rather than diminishes, since only by this means can the liquid be distributed with reasonable evenness over the hot surface, and only by this means can the duration of contact be made sufficiently short to prevent any accumulation of the liquid, the undesirable features of which have been discussed earlier.

In an intake system realizing this segregation of very finely divided fuel from the airstream, and its reasonably equal distribution over the surface of the chamber in which it is segregated, heat can be applied almost ad libitum to the walls of the chamber to hasten vaporization, without altering the final charge-temperature. Provided the chamber is neither too small nor insufficiently heated to vaporize the fuel, its size and temperature are without influence upon the temperature of the resulting charge, since the fuel takes on enough heat to vaporize it, and superheating of the vapor is prevented by the presence of and intimate contact with the incoming liquid spray, thus maintaining saturation and equilibrium between the vapor and the liquid.

But even in this case the possible low charge-temperatures discussed by Professor Wilson as supporting the entire fuel in the vapor state are not necessarily realized. When the fuel is separately vaporized and its vapor then mixed with the air, there is a definite temperature-rise in the air following the mixing, depending upon the heat of vaporization of the fuel used, the temperature of the vapor and the mixture-proportion. Therefore, if the entering air has a temperature so low that its value plus this definite temperature-rise upon mixing is less than that required to maintain the fuel as a vapor, some of the fuel will condense. Likewise, if the temperature of the air plus this temperature-rise gives a sum greater than that which maintains all the fuel as vapor, the charge, while entirely gaseous, will unavoidably stand at a temperature higher than that absolutely necessary for dryness.

[7] See THE JOURNAL, November 1921, p. 313.

(*Concluded on p.* 322)

Airplane Design and Performance Improvements Since the Armistice

By Lieut. C. N. Monteith, U. S. A.[1]

Dayton Section Paper

THE author presents, in outline only, the various features of airplane-development investigation that have been prosecuted. After mentioning the principal types of airplane designed and built shortly before the armistice and the types in service on the battle front at that time, four specific requirements for increasing the speed, the rate of climb and the ability to reach great altitudes are enumerated and commented upon, the further statement being made that an increase in performance can esult from any one or from a combination of all four.

Remarks upon design features are interspersed with the discussion of performance improvements, brief explanations being given of the variable-area and the variable-camber-wing schemes, the idea of having a thick wing-section with trailing and leading edges hinged, and that of modifying the wing-section by making the leading edge a small detachable airfoil that can be shifted. All-metal airplane construction is considered under four specific headings in conclusion.

IN presenting this subject briefly, it will be possible only to outline the various lines of investigation that have been carried on. Many of the improvements brought to the attention of the public within the past 2 years have been the results of work actually accomplished just prior to the armistice. Necessity for economy following the war has slowed up aeronautical research to an appreciable extent, and the production of airplanes in large quantities virtually has ceased. The Gordon Bennett race in France in September 1920 brought out several representative airplanes. With one or two notable exceptions, these were types that were under construction in the respective countries at the close of the war; every airplane entered in this race was a standard pursuit craft, but each had refinements made upon it for the race with the single idea of increasing its speed, which already was high. For instance, the Nieuport that won the race was a stock airplane with "clipped" wings; that is, the wings had less area than those built for the standard airplane. The American Army racer had been adapted to take a 600-hp. Packard engine in place of a 300-hp. Wright-Hispano engine.

It can be said that most of the airplanes that have been attracting attention were designed and built shortly before the armistice. This includes machines such as the Martinsyde Semi-Quaver, the English Nieuport Night Hawk, the French Nieuport No. 29, the Spad Herbemont, the Borel, the Thomas-Morse MB-3 and the Verville VCP. These airplanes have developed high speed, varying from 150 to 175 m.p.h., while those in service at the front at the time of the armistice, such as the English Sopwith Snipe, the French Spad XIII, the Italian SVA and the Fokker D-VII, showed high speeds of from 125 to 145 m.p.h.

Performance

An increase in performance, meaning speed, rate of climb and ability to reach great altitudes, can result from any one or from a combination of all of the following four sources:

(1) Engines of high power and lower weight per horsepower

(2) Reduction of parasite resistance, or the power required to pull exposed struts, wires, wheels and the like through the air

(3) An increase of speed-range; that is, the ratio of extreme high speed to the landing speed

(4) A decrease in structural weight for carrying the same load with the same factor of safety

The increased performance of the new airplanes mentioned above can be traced directly to the development of higher-powered engines of low weight. A comparison of the Spad XIII with the Thomas-Morse MB-3, for instance, shows that the number of wires and struts and other parasitic resistances is proportionately the same for each. In the airplanes in use on the front at the time of the armistice the power of the engines used averaged about 230 hp. With the development of the Wright-Hispano engine, weighing 632 lb. when dry and developing about 325 hp. at 1800 r.p.m., a large increase in power with a small increase in weight was available. High speed varies directly as the cube root of the ratio of power available, other things being equal. The average speed for pursuit machines at the time of the armistice being 135 m.p.h. for 230 hp., and the speed of the new airplanes averaging 150 m.p.h. for 325 hp., it will be seen readily that this relation holds and demonstrates that the increase in engine power is largely responsible for the increase in performance.

Design Features

Some German designers were endeavoring to increase the performance of their airplanes by the elimination of parasite resistance, making the wings thick enough to brace them internally and approximately as efficient as the thin wings. Professor Junkers and Herr Fokker did a great amount of work on this. The internally braced wing appeared in the Fokker triplane late in 1917, followed later by the Fokker types D-VI and D-VII biplanes. These were almost identical airplanes but had different engines. Dr. Junkers went even further and developed a single-seater fighting airplane similar to his passenger-carrying machine which is so well known in this Country, but only four of these were in commission at the time of the armistice, and they had inconsiderable service at the front.

A comparison of four airplanes will demonstrate clearly what is meant by the elimination of parasite resistance. Let us consider in the order stated the Curtiss JN-4D, the DeH-4, the Fokker biplane and the Junkers monoplane. The German experimenters have done much work on thick high-lift wing-sections, adapted to internally braced wings, but the English and French apparently do not favor this type of design. Their latest designs adhere closely to the conventional biplane having the strut and wire interplane bracing. The French de-

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signers have not, it seems, departed very much from standard practice, although some of their new designs vary somewhat from the standard arrangement with respect to struts and wires. American designers have not adhered to any one style, and the thick internally braced wing, the well known thin wings that require external struts and wires and a combination of both are appearing in new designs.

In connection with the internally braced wing, two very good sections have been developed during the past year by V. E. Clark, now chief engineer of the aeronautical department of the General Motors Corporation. The RAF-15, a thin section developed by the English, has been for some time the best section for ordinary thin-wing construction, and is generally used as a basis for comparison. The two sections designed by V. E. Clark, known as the USA-27 and the USA-27-C, compare very favorably with the RAF-15, as is shown approximately in Table 1. In this table the RAF-15 is taken as the standard.

TABLE 1—COMPARISON OF THE STANDARD THIN WING-SECTION WITH TWO THICK WING-SECTIONS

	Wing-Section		
	RAF-15	USA-27	USA-27-C
Efficiency at High Speeds	100	72	87.5
Efficiency at Cruising Speeds	100	81	86.0
Efficiency at Climbing Speeds	100	93	95.0
Front-Spar Depth	100	152	220.0
Rear-Spar Depth	100	184	256.0

Both of these sections are suitable for internal bracing, and are being used now by various designers on airplanes that give promise of being superior to any yet produced for the military or commercial purposes for which they are designed. The Cloudster, an airplane designed and built by the Davis-Douglas Co., of Los Angeles, Cal., has one Liberty engine and uses the USA-27 wing section. It is expected to carry fuel enough for a continuous transcontinental flight.

The development of the thick wing has made possible the design of large monoplanes in which the wings are thick enough to house the engines, thus reducing further the parasite resistance on airplanes mounting more than one engine. A recent German commercial airplane is a large thick-wing monoplane with four engines mounted in the leading edge of the wing.

The third method of improving performance is the increase in the speed-range. For airplanes that have a constant area and a fixed wing-section, the ratio of high to landing speed rarely exceeds 3 to 1, and in most cases it is nearer 2½ to 1; that is, if the speed range is 3 to 1 and the landing speed is 50 m.p.h., the high speed will be generally not more than 150 m.p.h. Two ideas for increasing the speed-range have been worked on for some time, but there has been no practical solution of either until recently. One is the variable-area wing; the other is the variable-camber wing.

Variable-Area and Variable-Camber Wings

The most notable of the variable-area-wing airplanes has been developed by a French designer. The wing is constructed so that large flat plates are carried under the leading and trailing edges, forming the bottom of the wing. These plates are extended when taking-off or landing, forming a wing of considerably increased area. The normal area is doubled in this particular airplane; consequently it supports the same weight at a much lower speed. The plates are drawn in for high speed and form a very efficient wing of small area. Results of complete trials on this airplane are not available, but it is understood that it was not entirely successful due to trouble with the operating mechanism. A satisfactory speed-range of from 37 to 125 m.p.h. was obtained; a ratio of 3.4 to 1.

Many so-called designers submit ideas for variable-area wings but, before building an airplane according to their ideas, it is necessary to determine whether the actual gain in lift afforded by their devices more than offsets the additional weight and complication of the apparatus necessary to control it safely. The idea of the variable-camber wing consists in changing the section of the wing so that it can be made to give a high lift for take-off or landing, and then change to a section that is very efficient at small angles of incidence for high speed. The matter of the extra weight of the operating mechanism versus the increased lift is again the determining factor in the feasibility of the idea. The most successful of the designs so far proposed is the racer built by the Dayton-Wright company for the Gordon Bennett race. In this case the leading and trailing edges of the wing were hinged so that they could be lowered for landing or taking-off, thus forming a high-cambered wing with a high lift-coefficient. They were raised for high speed so that the wing was comparatively flat, and efficient at high speed; also, the parasite resistance was decreased for high speed by the use of a retractable landing-gear.

Glenn L. Martin, an American designer, has developed recently a thick wing-section with the trailing edge hinged at a point 70 per cent of the way back on the chord, and the leading edge hinged at 15 per cent. With this combination and with the hinged flap down at a large angle, he has obtained a lift coefficient double that of the RAF-15; and, with the flaps set up at small angles so as to streamline the section, an efficiency is reached at high speed that is about 20 per cent greater than that of the RAF-15. We have every reason to believe that the tests are reliable and, unless there is some structural consideration that will bring the weight of the operating mechanism up to a prohibitive figure, this new section will permit a greatly improved performance.

The Handley-Page company, of England, has done a considerable amount of experimental work with an idea not altogether new but not so well known among designers as variable-area and variable-camber wings. It is to modify the main wing-section by making the leading edge a small detachable airfoil, shifting this small wing a few inches forward of the main wing by using a series of hinged brackets, or fitting it closely in place as the leading edge of the wing, as desired. The small wing is pushed forward for taking-off or landing, which gives the effect of an increase in area and improved lifting power; for high speed the small wing is brought back to its position as leading edge of the main wing, which provides a smaller area in conjunction with an efficient high-speed wing. Several modifications of this idea have been experimented with and flight tests have been made but, to date, we have received no reliable information as to the details of the device. These three devices and their modifications for improving the speed-range are still in the experimental stage, and have not been incorporated as yet in military types.

The fourth method, that of improving airplane performance by a decrease in total weight, has progressed steadily. The decrease in engine weight lies with the engine designer, but the structural weight is not reduced so easily. It requires long and careful research and tests to effect a combination of efficient design and

the most suitable materials. The three materials that have been most investigated are plywood, duralumin and alloy steels. Excellent progress on rib and spar design has been made and wing structures averaging 1.0 to 1.2 lb. per sq. ft. are easily attainable, even for internal bracing, but since the increased factors of safety that are required now for military airplanes require heavier structures, the two have practically offset each other.

All-Metal Construction

Metal construction in aircraft is not a postwar development. Ever since the first airplanes were built designers have been making attempts to use metal in various parts of their structure. Only recently, however, has the development of the high-strength alloy steels and duralumin made possible the design of an airplane structure that compares favorably, weight for weight, with the wood and wire construction that was formerly employed.

Metal construction has the following distinct advantages:

(1) The designer is assured of an homogeneous material, particularly when steel is used
(2) Metal is not subject to such variations in strength or size with changing atmospheric conditions as wood is; consequently, it is better for working under different climatic conditions. From the standpoint of war materials, metal is better for storage
(3) The use of metallic covering on the wings and the body gives a much longer life to the average airplane, and does not require the care in handling that a fabric covering requires
(4) With efficient design and planning, metal construction for production work can be turned out more cheaply than wood and wire construction

The Fokker type of fuselage, made of welded steel-tubing, and the Breguet fuselage, made of duralumin tubing and steel fittings, were the outstanding departures from wood construction during the war. Toward its close, however, the Junker duralumin construction made its appearance.

Since the close of the war all countries have been investigating the question of metal construction. The Germans have built some large flying-boats and land machines for passenger carrying, using duralumin throughout except for some of the more important members which are made of steel. Fokker, however, is using wooden wings, having plywood covering in his commercial machine. The French designers have not taken up metal-construction development very extensively, but the English have been doing considerable work on it. Their experimental stations have investigated a large variety of steel spars and wing constructions and obtained some structures that appear to be simple, light and effective. The Short company has built an entire biplane, including wings and tail surfaces, of duralumin. Apparently it is a success. The Vickers company has done some extensive work with duralumin, while the Boulton and Paul company is handling a large amount of metal construction. One of the English designers states that he has "reached the conclusion that for airplanes exceeding 2000-lb. gross weight metal construction is superior from every angle." It can be made lighter, stronger and at less cost than wood, and is more durable under all conditions. A large part of the design of metal airplanes is composed of efforts to simplify and reduce to a minimum the operations necessary to obtain the required parts and assemble them.

In the United States metal construction has been confined to experimental work. To date nothing has been done toward putting an all-metal airplane into production. Several airplanes of all-metal construction are now under consideration by the Air Service. They embody entirely new features as regards the construction of ribs, spars and coverings, and give promise of being distinct advances over anything now being built in Europe.

So far as actual construction is concerned, little has been done since the armistice that represents any appreciable advance over the work that was completed up to that time. The experimental stations have, however, made considerable progress in the investigation of the four methods of improving performance, and it is believed that, when the necessity for the strictest economy in Government expenditures shall have been obviated, larger appropriations will be made and the construction of aircraft carried along on a scale that their importance warrants.

VAPORIZATION OF MOTOR-FUELS

(*Concluded from p.* 319)

Average gasoline, when so handled in the intake, causes the charge-temperature to stand at substantially 60 deg. fahr. above that of the entering air, for a 15-to-1 mixture. Thus, to realize Professor Wilson's minimum dry-charge temperature, the entering air will be required to have a temperature of about 33 deg. fahr. Since the temperature of the entering air is almost always higher than this, such an intake system can be taken to give invariably dry charges to the engine.

Professer Wilson's dry-charge temperature for a 15-to-1 kerosene mixture at about atmospheric pressure is given as 230 deg. fahr. In the intake system just discussed, the temperature rise with average kerosene is 125 deg. fahr. The temperature of the entering air would have to be about 105 deg. fahr. to give dryness. Ordinarily, this latter temperature is much less than 105 deg. fahr., with the result that some of the kerosene vapor is condensed upon mixing with the air. Professor Wilson's charts show to what extent this condensation will occur with different temperatures of the entering air.

Internal-Combustion-Engine Power for Road-Grading Machinery

By C. O. Wold[1]

Minneapolis Section Paper *Illustrated with* Photographs

After dividing road building into three stages the author describes different types of road machine and the methods that apply to their usage, with a view to affording a basis for decision regarding the types of automotive vehicle best suited for furnishing power to these various road-building machines for the different stages of road work.

The subjects of large versus small tractors and the most suitable type of tractor are discussed in some detail, and engine requirements also receive attention. Such subjects as drawbar pull required, the use of multiple-unit road machinery behind one power unit, combination tractor and grader units, general utilization of power units, and the power requirements of concrete road construction also are commented upon at some length.

ROAD building can be said to divide itself into the three main stages of the construction of the grade, the surfacing of the road and road maintenance. Several methods are involved in building road grades under differing conditions. One is used in covering territory that is fairly level; another, used where the territory is hilly and where filling is required, is called the cut-and-fill method. A road machine of the blade type is used more particularly where the road has level stretches. The blade type of road machine is made in different sizes, usually designated by the length of the blade. For building a grade with one of these machines, shown in Fig. 1, a 10 to 12-ft. blade is, as a rule, the most economical up to a point where the grade is beyond a normal size.

To build a high grade, the elevating grader is used also. It is a machine with a plow on one side and an endless rubber belt, 36 in. wide, that carries the dirt from the plow and delivers it on the opposite side, as shown in Fig. 2, into a dump wagon, which hauls it away. The elevating grader is used commonly in such localities as the Red River valley. The grades are made very high there for two reasons; one is that this section needs the drainage and high grades not only drain the roads but also help to drain the country. A grade higher than the level of the surrounding country is very desirable where the latter often is covered with water. A low grade would be damaged by the standing water; a high grade remains above the water.

Grass or sod is not a desirable material in a grade and most highway commissions maintain that it should be taken out entirely. If sod is plowed from the side of the road and piled up, it creates a levee and prevents drainage, but it is very expensive to haul it away. The next best thing is to put the sod or rubbish into the middle of the grade and bury it where it will do the least harm. Rubbish, grass or sod has a tendency to hold moisture. For that reason it is not wanted in a grade, especially near the surface. Anything that holds or has an attraction for water is detrimental to the road, because we grade a road for the purpose of shedding the water and keeping the grade high and dry. The first cut taken with the blade machine removes the sod. That cut is made as shallow as possible; it is probably only 2 or 3 in. deep or just sufficiently deep to cut soil enough to scour the blade and lift the material toward the center of the road. The usual method is to go up one side and come back on the other side of the road, taking the first furrow where the bottom of the ditch would be and following the grade stakes. After the first furrow, another round is made just inside, shaving off some more sod and bringing it closer to the center of the road. Usually the

Fig. 1—A 12-Ft. Machine Building a Road in Heavy Gumbo

Fig. 2—Elevating Type of Grading Machine Discharging Material Removed from Road into Wagon

[1] Secretary, Russell Grader Mfg. Co., Minneapolis.

roadbed is about 36 ft. wide between the center-lines of the side ditches and two rounds will not bring the material into the center of the road. The roadbed width varies in different localities and States. Iowa, for instance, calls for a wider road than Minnesota.

When these two furrows have been taken off, the machine is run on the outside and shaves off the outer edge or slope that is to incline from the outside into the ditch, often referred to as the back slope of the ditch. Another thin cut of sod is then taken and deposited near the center-line of the ditch that is to be. On the fourth round, the machine cuts 12 or 15 in. deep. It moves in a large volume of earth and with it the windrow of sod. The sod, being lighter, moves inward ahead of the subsoil as the machine pushes it. After the fourth round, we begin to drift the material to the center of the road, which requires about three more rounds. It will be noted that at this stage we drift four furrows toward the center of the road. One reason for this method is to allow the tractor to run in the center of the road as long as possible, where it is on solid ground, before bringing loose dirt into the center. The tractor can go back and forth in the center of the road while it is making these four or almost five rounds, before it travels on the loose soil. This is one reason why it is more practicable to use one machine back of the tractor than two.

These seven rounds result in a moderate grade and a ditch probably about 12 in. deep, depending upon how deep a cut the machine can make and how much power is available. The process is repeated and a second cut is brought in from the ditch and, after five rounds more, the earth has reached the center fully spread. About 12 rounds represent the requirement of an ordinary grade over an ordinary stretch of country, using a 12-ft. machine. This work should make a road having an 18 or 20-in. ditch and a crown of a corresponding height above the grade. With a 10-ft. machine a few more rounds are necessary because the machine cannot drift the material so far each time. With the 12-ft. machine about 25 to 35 hp. is required at the drawbar; the 10-ft. machine requires about 20 to 25 hp. at the drawbar. More than 25 to 35 hp. would be an advantage for the 12-ft. machine, but such extra power might be superfluous from a commercial standpoint since 25 to 35 hp. is sufficient.

The tractor is run in the center of the grade, and the draft is transmitted through the 10 or 11-ft. pole on the grader and a cable about 24 ft. long. This permits the grader to be guided to the outside of the ditch, because the grader pole is offset and is adjustable; usually it can be offset from the operator's platform on the grader. An adjustment rod extends back from the pole so that it can be swung one way or the other. The operator steers the grader where he wants it to travel, regardless of where the tractor travels.

Elevating graders are used wherever possible in cut-and-fill work. In certain localities, steam shovels are used. Steam shovels can be used where a grader cannot, but, where the work is such that an elevating grader can be used, I believe the work can be handled more cheaply with an elevating grader than with a steam shovel. The elevating grader requires about 25 hp. at the drawbar. When it is used to cut down a knoll or hill, the dirt usually is loaded into 1½-cu. yd.-capacity dump wagons and hauled away by teams of horses.

Large and Small Tractors

I have not seen much dump-wagon work done with tractors, but perhaps it could be done to advantage in most cases. On one job in Kansas City, Mo., I saw a 10-ton tractor used with three 3-cu. yd. wagons hooked back of it. These wagons had been built especially for tractor purposes. The tractor cannot very well be used for hauling dirt away because of the necessity of running it into low places and through loose material at the dump, or perhaps to a dumping-off place having a descent of from 5 to 25 ft. The tractor must then go down the grade that is being built and return on the outside of it. This is not very desirable work for a tractor, although the outfit I observed in Kansas City was operating well. One objection to the use of a 10-ton tractor that hauls three large-sized wagons is the length of the cut required. An elevating-grader cut is very short, usually, and the run one way would not be long enough to fill three wagons of large capacity. It could be used to advantage when working on a long cut and a long haul. With a 10-ton tractor, where three wagons can be filled without turning around, such an outfit will replace six to nine teams of horses in removing the dirt to the dump.

The small creeping type of tractor has been used for hauling the dirt wagons and it seems to be practical, but I have not seen a wheeled tractor used for this purpose. The various types of tractor have their proper place in road work, inclusive of caterpillar, four-wheeled and two-wheeled tractors. Any one of these types may have an advantage over the others under certain conditions. Most tractors are somewhat weak for road-building work, especially with respect to their wheels. The ordinary farm tractor is hardly suitable for road work and is not spring-mounted. Several tractor-building companies are making special tractor wheels for road work, but that matter is overlooked generally and the ordinary farm tractor has been used with poor satisfaction. Strong wheels are required for road work; the ordinary farm-tractor wheel is not nearly strong enough.

Tractor Engines and Tractor Types

Tractor engines for road work should be of the heavy-duty type. Most users of road-work tractors think that the engines are far from being of the heavy-duty type. In the West we have observed that many tractors that have been tried for road building are somewhat lacking in power. I have heard it said often that an engine having a large bore and a short stroke is more desirable in a tractor used for this purpose, but I cannot vouch for the truth of this. However, it seems to be the popular opinion. A tractor engine loses 3 per cent of its power for each 1000 ft. of elevation above sea level. In Western territory we are working at altitudes of 3000 to 6000 ft., which causes an appreciable reduction in engine power.

The track-laying type of tractor seems to have gained much favor with road builders and it is especially suitable for cut-and-fill work. Tractors used for road work should be slow-moving. Slow-speed tractors give much better satisfaction and last longer on road jobs than those having higher or variable speeds. With variable speed capacity at his command, the operator often misuses the high speed and, if the tractor weighs 10 tons or more and is put over the road too fast, it destroys the journals within a short time. The large tractors that have had the greatest success in road building have been those having a speed less than 2 m.p.h. Another reason that the track-laying type of tractor has found favor in many places for construction work is that such a tractor can be run safely over small bridges. We do not find that consideration so important in Minnesota, South Dakota, Nebraska or even in Iowa, because the small bridges there are strong enough for heavy threshing rigs to

cross them. But in many districts of the South and in other parts of the Country where such heavy rigs are not transported from place to place, the small bridges would not be strong enough to carry wheeled tractors that are large enough for road construction work.

Road construction involves much scraper work. Work on the approaches to bridges and a considerable amount of the road finishing work must be done with scrapers. A few attempts have been made to use tractors for hauling scrapers. In some instances the small types of tractor have been used for hauling one or two-wheel scrapers behind the tractor with good success, but this usage is still in the experimental stage.

I think it is better to use one large road machine behind a large engine than to use two smaller graders. If two graders are hauled by one engine, one of them must idle to a great extent and the two are a nuisance in turning. In the process I described for bringing in two or three of the outside furrows of sod and waste material to the center of the grade, the second trailing grader is not doing much work. About the most that this would accomplish is to shorten the process by two or three rounds and more time would be lost in trying to do that than could be saved. Another man is needed to operate the second grader, and one does not obtain the desired efficiency. I have seen one grader operated on one side of the road and one on the other side, simultaneously, but this is inefficient because the graders will interfere with each other at the center of the road. The idea of using two tractors in front of one grader has been advocated and I believe it is better than that of using two graders behind one tractor.

Construction work is only a short job when compared to that of road maintenance. When the building of the grade is completed, there is very little more of that kind of work to do, unless it be to change the road or straighten it. If the two-tractor plan of road construction can be used, and I see no reason against it, the expense of a large tractor for construction work would be avoided and the small tractors would be available for road maintenance. Many townships and some counties cannot afford to buy tractors and are dependent upon some one else to furnish them.

Some agitation for the building of a grader and tractor in one unit for construction work has developed, but we do not think this can be done with any degree of satisfaction. The expense of combining a large tractor and a large road machine into one unit is not warranted for the purpose of construction work only. It would have only a limited use during the building of a grade, and an expensive machine of that kind entails a loss during the time it cannot be used. Another bad feature of a combined grader and tractor is that the grader must travel in the ditch and that is no place for a tractor. It cannot get proper traction and the tractor must work on an incline, causing excessive wear on the bearings. The tractor works better in the road.

General Usage

Gravel or crushed rock is commonly used in surfacing a road. Minnesota has much gravel and good road material that can be taken out of a bank almost anywhere and put upon the road, but in other sections road-surfacing material must be shipped in. Crushed rock and shipped material must be placed in a loading bin and hauled from there to the road. Tractors with trailers and motor trucks are being used for such hauling; it is an open question which will prove to be the most practical. Tractors used for this purpose must be equipped with wide wheels so that they will not injure the roads in hauling material to that part of the road which is being surfaced. This is essential. In surfacing roads with gravel or rock, it makes little difference whether this work is started from the near or from the far end. If it is started from the near end, the road is greatly worn down before it is completed. If it begins at the far end and the grading is in the direction of the source of gravel supply, the contractor finds that his tractors or conveyances are digging deep ruts and packing the material down in the center. These ruts require from 20 to 25 per cent more gravel than if they did not exist and, although this may not be detrimental to the road, it is more costly. The same thing is equally true regarding the use of tractors or trucks. The 5-ton trucks used for this purpose encounter the same trouble. Most trucks tear up the road too much during hauling. It seems clear that we must come to the use of a smaller rather than a larger truck. A 2½ or 3½-ton truck equipped with pneumatic tires will cause less wear on the road.

A fleet of trucks for hauling gravel probably is more expensive and from that point of view the advantage is with the tractor, but certain contractors have abandoned the tractor and trailer system and installed fleets of trucks. They claim they are benefited thereby. Such a case is reported from one of the Western cities, where a contractor replaced tractors and trailers and has now had trucks in use for about a year. However, he was graveling the streets in the outskirts of the city, and for such use trucks might be more advantageous than tractors and trailers. The experience of a certain contractor in northern Wisconsin is interesting. He hired his graveling outfit. He had been using trucks but found that they cost him too much. They injured the roads when he tried to gravel them from the near end, as he was forced to do, and there was a great amount of repair work. He declared his intention of installing tractors and trailers the next year. This is a matter that must be worked out. Possibly both systems will be used because of the varied conditions; they are competing now for the business, which is still in its infancy. However, more tractor power will be required for surfacing roads than for all of the other work.

Concrete Road Requirements

Much hauling will be required in building what are called permanent roads with a concrete foundation. There seems to be a demand at present for a conveyance to transport the wet concrete from the mixer to the work. The present method is to use a large mixer equipped with a boom and a bucket to bring the concrete from the mixer to the point where it is to be poured. Many contractors are not satisfied with this method, because they think the concrete mixer should not be moved so often. They believe it should be brought a little farther ahead and have the material brought to it as well as transported from it. They often use trucks for bringing the material to the mixer, the concrete being loaded into small tractor conveyances and transported to the work. The smaller types of caterpillar tractor are used also to take the material to the mixer and haul the concrete to the road. There is a large opening for small tractors for this purpose.

Smaller tractors are more useful for road maintenance, but wheeled tractors are used to a larger extent for this purpose. Blade machines of the type shown in Fig. 3, equipped with 5, 6, 7 or 8-ft. blades, are used in maintenance work. A tractor is used with these machines

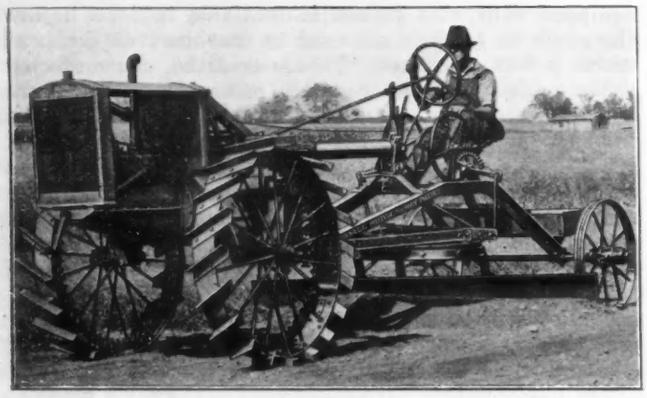

FIG. 3—A 6-FT. MAINTENANCE MACHINE THAT IS EMPLOYED FOR HIGHWAY PATROL DUTY

that varies from 8 to 10 hp. at the drawbar. There is room for another piece of equipment that will run with a somewhat larger blade, a larger machine for more extensive repair work rather than maintenance. This requires from 15 to 18-hp. at the drawbar. There is use also for a lighter machine with a long blade which takes a wider swath for maintenance. Such a machine is shown in Fig. 4. It has a 3-section blade that is adjustable and can be conformed to the contour of the road. Each section is 5 ft. long, making about 15 ft. of blade. It is a machine weighing about 3500 lb. and can be handled with a small tractor having about 15 hp. at the drawbar. The popular demand for road-construction work is for a tractor having from 20 to 25 hp. up to 30 to 35 hp. at the drawbar. For maintenance work the demand is for a tractor having 8 to 10 hp. or one with about 15 hp. at the drawbar.

There seems to be an idea that a combination tractor and grader can be used to good advantage for road maintenance work. We have built a new machine that seems to take well, but we have not tried it out to any great extent. Maintenance work is much different from construction work. In maintenance work the machine naturally travels on top of the grade. The conditions are more favorable; the machine does not need to go into the ditch. Therefore, a tractor and grader combined into one unit may prove desirable.

THE DISCUSSION

E. R. GREER:—You mentioned less than 2 m.p.h. as being probably the best speed for grading purposes and simply specified a certain size of grader for a certain horsepower at that speed. At what speed would you expect it to require that amount of horsepower?

C. O. WOLD:—I draw a distinction between road construction and road maintenance. A tractor doing the heavy work of construction should run slowly; a maximum speed of about 2 to 2½ m.p.h. is fast enough.

R. S. KINKEAD:—What tractor speed should be used for maintenance work?

MR. WOLD:—They try to run 3 to 4 m.p.h.

A MEMBER:—What type of wheel lug is used on a tractor for road work?

MR. WOLD:—For road construction large lugs must be used. Those of the angle type are most popular. For road-maintenance work the lugs must be of a type that will not deface the road too much. A cone-shaped lug is suitable for that purpose, rather than a cleat or angle-type lug.

A MEMBER:—Are solid rubber tires used on tractors?

MR. WOLD:—Rubber-tired wheels would be fine for maintenance work and they are used on certain types of tractor, but the expense might be too great. Some four-wheeled tractors use them.

MR. KINKEAD:—Is it likely that a four-wheel-drive type of tractor will be developed?

MR. WOLD:—That type would have a large field. The cost would be an element. The ordinary user might endure certain disadvantages rather than pay a higher price for a tractor that is built to overcome them. What has been said about a four-wheel-drive truck might apply to a four-wheel-drive tractor. The four-wheel-drive truck is undoubtedly very efficient under certain circumstances; for instance, it will climb out of a gravel pit with a load much more easily than a two-wheel-drive truck.

MR. KINKEAD:—Do you feel that a light tractor is able to get sufficient traction in most cases?

MR. WOLD:—Yes, if it is not used under unfavorable circumstances. It should not be used when the road is muddy; the road should be fairly dry before beginning the work. Under such conditions it apparently has traction enough.

J. A. SKARNES:—What drawbar pull is required for the removing of a certain projected area of soil, for the different kinds of soil? If a 14-in. plow requires an average of about 700 lb. drawbar pull to pull it through the average soil, it will require much less in sandy soil and much more in gumbo.

MR. WOLD:—We are not in the tractor business, and we have not compiled such data. We do not attempt to advise the customer what horsepower he should have to run the grader. We find out what power he has and advise him what grader to use for that particular tractor with that particular power.

MR. SKARNES:—At what angle are road scrapers run so that they will scour most efficiently?

MR. WOLD:—That depends upon the nature of the soil. They are adjusted to an angle that will cause them to scour freely; it would in all cases be less than 45 deg.

MR. SKARNES:—As the angle of the scraper becomes greater that of course means a greater side-draft on the grader.

MR. WOLD:—Yes, but that strain does not come on the tractor; it reacts on the four wheels of the grader. The grader is on the side of the road and the tractor is in the center. The side-draft from the pull of the engine on the grader is very small. At first we had difficulty in convincing users of graders that the side-draft was not too great. We even put an ordinary lumber wagon between the tractor and the grader and hooked the grader

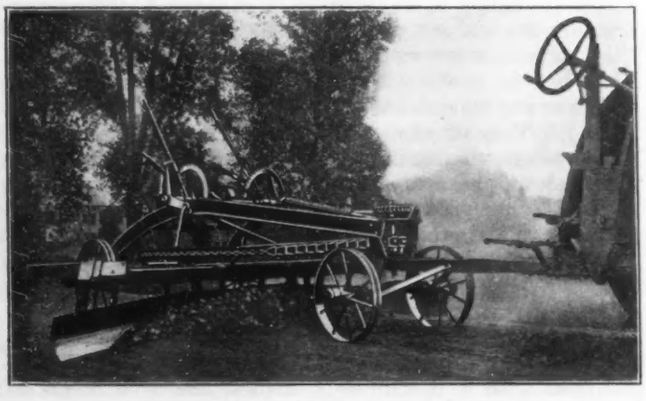

FIG. 4—A 15-FT. MAINTENANCE MACHINE

cable to the rear of the lumber wagon. We could go right along with a good-sized load on the graders without pulling the lumber wagon sidewise. That demonstrated the small amount of side-draft.

A. F. MOYER:—What success have you had in using two engines to pull one road machine?

MR. WOLD:—That has not been tried to any great extent.

MR. MOYER:—As most tractors are equipped with governors it would be necessary to have two engines with exactly identical road speed, or perhaps resort to a special governor adjustment to avoid having one engine take all of the load while the other one idled.

H. J. MAYER:—In maintenance work is it practicable to use more than one grader at a time?

MR. WOLD:—Our former maintenance machine was designed to take about a 15-ft. space on both sides of the road center, covering the entire road in one swath. We discontinued building it because it interfered with road traffic. In very few localities can one go out on one road and return on some other; one generally must go and return on the same road. If one must travel back and forth on the same road, one might as well confine the work to one side going out and to the other side coming back. On one occasion we sold six two-winged machines called planers to certain county commissioners in Iowa for use on heavily traveled roads. The commissioners were not satisfied with stopping occasionally to allow the traffic to pass. They wanted to get the roads fixed and kept on working, which raised a storm of objection because they held up traffic. The same objection applies to using two graders.

J. L. MOWRY:—Regarding the danger to gravel roads because of the use of trucks and tractors, the trouble is with the specifications under which the road is being constructed. If the road is damaged before it is completed, it cannot be expected to stand up afterward. These machines can do the work and the road will stand up if the specifications are all right.

MR. WOLD:—You must remember that the road is in process of construction. If you had a finished road with such a surface that it would carry tractors, there would be no need to put the gravel on it. On the other hand, when gravel is used, it is done largely the first time while the road grade is fresh; it has not been driven on to any great extent and has not had a chance to settle.

MR. MOWRY:—That should be a part of the road construction.

MR. WOLD:—That might be true from one standpoint but not from another. You might say that a dirt road should be built so that it can be driven on as soon as it is completed. That may be true with a more permanent road, but even in that case one cannot drive on it until it is dry and has set. The gravel or crushed-rock road also must set; as a matter of fact, it is a water-bound road.

A MEMBER:—Miles and miles of graveled road were ruined by driving the wagons in one track up and down the road in a certain locality of which I know, and it had to be plowed up afterward. The travel made two ruts that were as hard as adamant; the remainder of the road was loose and never worth anything.

MR. WOLD:—Using large tractors with trailers, when they are driven on different tracks along the road, tends to make a good road; it would be harder to do this with trucks or single units.

MR. KINKEAD:—What is your opinion of a tractor built along the lines of the Gray tractor with a drum? Would that be beneficial?

MR. WOLD:—The wagons would be needed just the same.

A MEMBER:—In the case I cited the gravel was being hauled 3 miles with trucks. I watched the operation very carefully for about 4 days; the trucks were ruining the road by hauling the gravel over it.

MR. WOLD:—For that reason I would recommend lighter trucks and pneumatic tires; they would not injure the roads so much. In one case the drivers were instructed to drive different places on an avenue under construction, so that they would not ruin it.

A MEMBER:—The trucks I mention were heavy 5-ton trucks.

MR. WOLD:—There is an apparatus for weighing the load on each truck tire. It is used in connection with the truck load that can be carried on a given width of tire. It is made in the form of jacks. They are set up under the axle, one at each wheel, jacked up and the number of pounds on each wheel is indicated. The pressure per inch of tire width is computed to determine how much the truck is taxing the road.

A MEMBER:—Would not the proper method in most of the road building in the Minnesota section be to drive on the side of the road? That is done in road building in California, except in maintenance work.

MR. WOLD:—No, it is impracticable here. It might be all right in dry weather but, as a rule, it cannot be done after rains.

A MEMBER:—But it is not necessary to work on the road at such times.

MR. WOLD:—It is necessary. We build roads at all seasons of the year.

MR. GREER:—Will Mr. Wold tell us something about snow-removing machines?

MR. WOLD:—We are developing a snow-plow for installation on a truck. We have built a snow-plow for clearing sidewalks and one for installation in front of tractors. Their use has not been extensive enough to be much of a guide. A snow-plow will work very satisfactorily on a truck. I understand, however, that truck builders object to it because it is too hard on the truck. A snow-plow would be very good on a tractor. We think it is a coming thing and that something of the kind will be required as the roads become all-year roads. The snow must be cleared from country roads the same as from city streets. Snow-plows on trucks are being used in New York City, but that is not practicable under our conditions because we usually have sleet in this section of the Country and generally the snow freezes before we can begin its removal.

MR. SKARNES:—What is the proper kind of road to build in Minnesota? We are appropriating much money for road building. Are we to build roads that in 10 years will still be roads, or will they be what we have today?

MR. WOLD:—I believe that there is no such thing as a permanent road. What are called permanent roads are no doubt more desirable for the traveling public; but we cannot build all roads that way because the amount of money available is insufficient. The next best thing is ordinary dirt roads with a gravel or a crushed-rock surface, and I am inclined to believe that they are, all things considered, the cheapest.

The Fundamentals of Internal-Combustion-Engine Design

By L. H. Pomeroy[1]

Cleveland Section Paper

THE factors affecting the performance of four-stroke-cycle engines are specified and the thermal efficiency and power obtainable from a given engine are stated to be dependent upon the compression-ratio, other things being equal. These features are elaborated upon and the subject of efficiency is treated at considerable length. Engine speed and friction losses are treated in some detail.

Mechanical-construction problems are enumerated and commented upon, inclusive of the respective merits of the long- and the short-stroke engine, the author favoring the latter. Three cardinal points in the design of an engine for automotive use are stated and discussed, and detailed considerations of the mechanical aspect of engine design appended.

A NEW engine design is practically determined by commercial considerations relating to manufacturing economy and public prejudice as visualized by the sales department, but there are certain fundamental problems that are common to all engines. The proper realization of these fundamentals is essential, to satisfy the commercial principle of getting the greatest value for the money expended, whatever the type of the engine may be.

The factors affecting the performance of four-stroke-cycle engines can be grouped as follows:

(1) Compression-Ratio
(2) Mixture Proportions
(3) Heat Losses
(4) Volumetric Efficiency
(5) Mechanical Efficiency

The thermal efficiency and the power obtainable from a given engine are dependent upon the compression-ratio, other things being equal. This does not imply that an engine with a high compression-ratio is necessarily more efficient or powerful than the same engine with lower compression. Much controversy would have been avoided if there has been a clearer understanding of the various practical considerations underlying the phenomena occurring in engine cylinders, particularly those of limited dimensions as used on automobiles, but the above statement holds true if the other things are equal.

The compression-ratio is the deciding factor as to what fraction of the fuel supplied is actually turned into mechanical energy. This fraction is wholly independent of whether the amount of heat supplied is large or small; that is, whether the throttle is open or partly closed. To avoid confusion due to variation in fuel composition, the air-cycle standard was adopted many years ago on the assumption that the working fluid was dry air. The air-cycle efficiency for an engine of a given compression ratio is

$$E = 1 - (1/r)^{\gamma - 1}$$

where

E = the air-cycle efficiency
γ = the ratio of the specific heat at a constant volume to that at a constant pressure or 1.408
r = the compression-ratio

[1] M.S.A.E.—Consulting engineer, Cleveland.

Substituting the value given for γ we have

$$E = 1 - (1/r)^{0.41}$$

This is the foundation of all engine calculations relating to efficiency and power. It will be seen from Table 1 that the efficiency increases rapidly from low to medium compressions and thereafter much more slowly. For this reason there is no great incentive to adopt higher compressions than those at which everyday fuel can be used conveniently.

TABLE 1—EFFICIENCY AT DIFFERENT COMPRESSION-RATIOS

Compression-Ratio	Efficiency, per cent
2 to 1	0.242
3 to 1	0.356
4 to 1	0.426
5 to 1	0.475
6 to 1	0.511
7 to 1	0.540

Unfortunately, the mixture used in internal-combustion engines does not behave as a perfect gas and a somewhat formidable series of deductions are necessary before the air-cycle criterion of efficiency can be applied intelligently. The addition of heat to the working fluid due to the explosion increases the temperature of the mixture very greatly, but not to the extent that is given by simply calculating the temperature increase of the mixture by knowing its mass, specific heat and the total heat supplied. Accounting for this discrepancy has been the task of able scientists for many years and it is only now that anything like definite knowledge is being obtained. Broadly, the effect is as if the specific heat of the mixture were increased at high temperatures so that the increase in temperature is less for a given heat supply than would be the case otherwise. Actually part of the discrepancy is accounted for by direct radiation of heat to the cylinder walls and part of it by dissociation. The important matter to the designer is that the loss due to so-called change of specific heat is tolerably constant and fortuitously independent of the nature of the fuel or the mixture strength. It is unavoidable and must simply be accepted. Its mean value can be taken as 16 per cent of the air-cycle efficiency.

The necessity for maintaining cylinder walls, pistons and valves at a sufficiently low temperature to insure lubrication and adequate cooling reduces the available heat still further by something between 12 to 20 per cent of the air-cycle efficiency, the amount depending upon combustion-chamber design in general. A small deduction also must be made on account of incomplete combustion and early opening of the exhaust-valve. This cannot be reduced to much below 3 per cent. The efficiency attainable is less for these reasons than that indicated by the air-cycle efficiency and amounts to some 63 to 69 per cent thereof. The loss due to the change of specific heat is outside the control of the designer, but that due to direct cooling and incomplete combustion

merits the most careful consideration and its reduction is the essential thermodynamic problem in engine design.

Relative Engine Efficiency

The relation between the efficiency actually obtained and the air-cycle efficiency is known as the relative efficiency of an engine. It may vary, owing to the losses previously mentioned, from 60 per cent in a good engine of standard design to 70 per cent in a very well designed engine in which every care has been taken to suppress the said losses. When the relative efficiency is known, the indicated thermal efficiency is calculated by multiplying the air-cycle efficiency appropriate to the compression-ratio used, by the relative efficiency. The extent to which any given engine falls short of this in indicated thermal efficiency is a measure of what development can be made without fundamental alterations.

The mixture proportions that can be used in any standard type of gasoline engine vary roughly from 70 to 130 B.t.u. per cu. ft. of mixture supplied. Actually, the mixture strength used in normal working is about 100 B.t.u. per cu. ft. and, on this basis, the indicated mean effective pressure can be calculated. For example, taking the compression-ratio at 5 to 1; the air-cycle efficiency, 47.5 per cent; the relative efficiency, 62 per cent; the indicated thermal efficiency, 29.4 per cent; 100 B.t.u. supplied per cubic foot of mixture; and 77,800 ft-lb. per cu. ft.; the number of foot-pounds available per cubic foot is $(77{,}800 \div 100) \times 29.4 = 22{,}800$ or 13.2 ft-lb. per cu. in. The number of foot-pounds per cubic inch of mixture obviously represents its energy. The pressure per square inch or indicated mean effective pressure is obtained by multiplying this number by 12. In this case it is 158 lb. per sq. in. which, moving through a distance of 1 in., is equivalent to the energy per cubic inch. However, this calculation involves the assumption that the mixture burned is at 32 deg. fahr. and a pressure of 14.7 lb. per sq. in. at the end of the suction stroke. Unfortunately, this is an impossible condition in the normal engine. The mixture on passing into the cylinder is heated by contact with the hot wall of the cylinder, the piston and the valves. It is impossible also for the mixture to flow into the cylinder without a certain pressure-depression relatively to the atmosphere.

Volumetric Efficiency

The extent to which an engine can avail itself of the mixture supplied per revolution is known as its volumetric efficiency and is primarily dependent upon the pressure and temperature of the mixture at the end of the suction-stroke, excluding the rise of temperature due to the residual exhaust-gas in the cylinder from the preceding exhaust stroke. So long as the pressure of this residual exhaust is not in excess of the incoming mixture, its temperature has absolutely no effect upon volumetric efficiency because it is obvious that this exhaust can be considered as being entirely separate during the suction-stroke and only mixing with the incoming mixture at some later period of the cycle. If, then, 100 per cent volumetric efficiency is that obtained when a charge volume equal to the piston displacement is drawn in at 32 deg. fahr. and 14.7-lb. per sq. in. pressure, it is possible to estimate what the volumetric efficiency may be under practical conditions. If the atmospheric temperature is 60 deg. fahr. and the resistance due to valve-port restriction is 0.5 lb. per sq. in., the only other factor required is that of the rise in temperature due to contact with hot cylinder-walls, pistons, valves and the like. In general, this temperature-increase will not be less than 115 deg. fahr. The volumetric efficiency attainable is, therefore, inversely proportional to the absolute pressure 14.2 lb. per sq. in. and an absolute temperature of 333 deg. cent. (599 deg. fahr.) of the mixture at the end of the suction-stroke; that is, $(491 \div 599) \times (14.2 \div 14.7) = 79.5$ per cent. There are many published figures in excess of this, but they can be disregarded without risk. The figure previously given of 158 lb. per sq. in. indicated mean effective pressure must, therefore, be reduced by multiplying by the volumetric efficiency to bring it into line with actual working conditions. It thus becomes $158 \times 79.5 = 125.6$ lb. per sq. in. This can be considered the maximum attainable under the prescribed conditions.

Engine Speed

The indicated mean pressure already mentioned presupposed a pressure-drop in the induction system of 0.5 lb. per sq. in. At high engine speeds this drop is considerably larger and, according to Ricardo, the volumetric efficiency expressed in terms of inlet gas velocity becomes less than 60 per cent when this is over 250 ft. per sec., as is shown in Table 2. My own experiments do not corroborate this but indicate that the effects due to inlet-port and valve friction reduce volumetric efficiency from 79 to 75 per cent, over a gas-velocity range of from 100 to 300 ft. per sec. Ricardo's deductions were made from an examination of many engine tests and fortuitously represent the facts. It would appear, however, that the effect of internal temperature on volumetric efficiency has been neglected completely and the whole loss related to port and valve restriction only. If this point can be established, as experience seems to show, it is possible to use smaller valves than hitherto considered necessary, with the very important advantages of better turbulence and a more compact shape of combustion-chamber.

TABLE 2—RICARDO'S VALUES FOR GAS VELOCITY AND VOLUMETRIC EFFICIENCY

Gas Velocity, ft. per sec.	Volumetric Efficiency, per cent
100	80.5
120	79.0
140	77.0
160	75.0
180	72.0
200	69.0
220	66.0
240	62.0

Turbulence is the necessary state of commotion in the mixture to obtain complete combustion at the speeds used in automotive engines. It is dismissed usually by the statement that a gas velocity of from 130 to 160 ft. per sec. is essential for adequate turbulence, but nothing is said about the engine speed at which this velocity should be attained. It is obvious that, for automobile engines working over a wide speed-range, the specification of a desirable gas-velocity to insure turbulence is meaningless unless the engine speed also is specified. Fortunately, the gas velocity that is appropriate to adequate turbulence seems to be lower than is prescribed by general conditions of design; that is, it needs a large departure from accepted practice to make valves large enough to obtain such low gas-velocities as to affect turbulence adversely.

My experiments on this point[3] indicate that there is

[3] See *Proceedings of the Institution of Automobile Engineers*, vol. 13, p. 163.

substantially no difference in turbulence at 800 r.p.m. between gas velocities of 56 and 150 ft. per sec., but no difference could be detected at 2000 r.p.m. between gas velocities varying from 167 to 200 ft. per sec. Consideration of the point that high gas-velocities can be used without great reduction in volumetric efficiency indicates that the line of attack in improving existing engines to make them capable of delivering the power that is undoubtedly in them is to study combustion-chamber and piston design to reduce direct heat-losses and internal temperature. It should be mentioned also that neither gas restriction nor internal temperature affect the indicated gas consumption. Indeed, the only effect, even upon the brake gas consumption, is in respect to reduced mechanical efficiency. The reason for this is that the thermal efficiency of an internal-combustion engine depends upon the compression-ratio and not upon the temperature or pressure of the mixture at the beginning of compression.

The indicated mean pressure is a measure of the torque exerted by the engine before overcoming the internal friction thereof. The brake mean pressure is obtained from the indicated mean pressure by subtracting the engine friction expressed in terms of pounds per square inch of piston area. This internal friction due to the sum of gas and mechanical friction and over a speed range of from 400 to 2800 r.p.m., from reliable tests of two engines of very different design, is as shown in Table 3.

TABLE 3—INTERNAL ENGINE-FRICTION

Engine Speed, r.p.m.	Engine Friction per Square Inch of Piston Area, lb. Four-Cylinder 4¼ x 4¼ in.	Six-Cylinder 3⅜ x 5½ in.
400	6.0	7.0
800	8.4	8.9
1,200	11.2	12.0
1,600	14.9	14.9
2,000	17.6	17.5
2,400	20.9	20.8
2,800	23.0	24.0

It is of interest to note that the weight of the six-cylinder-engine piston complete, with wrist-pin and rings, was 1.5 lb., and the weight of the four-cylinder-engine piston in a similar condition was 2.4 lb. The total reciprocating weight was, therefore, as 9.0 is to 9.6 and the piston friction in each engine is such that the difference between the two is probably less than the difference that would be noticed between a series of engines of either type. These are good average figures for well-made engines with forced lubrication and aluminum pistons. Subtracting these piston-friction values from the indicated mean pressure as previously obtained, the brake mean pressure and, consequently, the power obtainable at any given speed can be determined. The indicated mean pressure already calculated is that obtainable under the conditions of minimum gas-restriction and internal cylinder-temperature. The effects of these two taken together are given by Ricardo's figures as shown in Table 2 and, in the present state of knowledge, these are a safe guide.

Internal Engine Friction and Summary

To determine the brake mean pressure over the complete speed-range it is therefore necessary to use the volumetric efficiency applicable to the gas velocity at each engine speed in calculating the indicated mean pressure and then to deduct therefrom the appropriate friction losses. I have indicated the pitfalls in this procedure but, in the present state of knowledge, it is the best that can be done and such a calculation will usually show the extent to which most engines fall short of what can reasonably be expected.

Attention is drawn to the great importance of minimizing internal friction in any engine that works at very partial throttle, as is the case with all automobile engines. The internal friction can easily equal the horsepower actually developed; that is, the mechanical efficiency may not exceed 50 per cent under running conditions, so that even a small reduction in the engine friction may have a very powerful effect upon the gas consumption.

Summing up, the brake thermal efficiency of an automotive engine is dependent upon the compression-ratio, the mixture strength and the mechanical efficiency. The possibilities of improvement lie in the use of higher compression and the reduction of direct cooling and mechanical friction losses. The power obtainable, from the thermodynamic viewpoint, depends upon the compression-ratio, the volumetric efficiency, the mixture strength and the mechanical efficiency. Considerable possibilities of improvement lie in the study of internal engine-temperatures, combustion-chamber shape and the reduction of internal friction.

The question of mixture strength is not of great practical importance as the mixture proportions that can be used are limited and, incidentally, can easily be made adjustable; also, the best mixture for maximum torque is about the same as that for maximum efficiency. In the automobile engine, however, there are many considerations other than thermal efficiency and maximum torque. It is absolutely essential to possess the ability to accelerate without hesitation; the vast majority of users judge power by the capacity to accelerate, although these two qualities are distinctly separate. It is in this aspect of the question that the carbureter expert steps in and, by the larger wisdom arising from an extended experience, supplies the knowledge without which an automobile engine may possess all the virtues but be bereft of charm. This is indeed a field in which progress has been made by practice rather than by mathematical theory. The whole literature of practical carburetion is a mist of vague speculation, contradictory theories and intensive groping for the light. As such, I will leave it with the one remark that he who designs automotive engines should consult the best carbureter expert he knows before putting his pencil to paper. This concludes the summary of what may be called the general theory of design with respect to efficiency and power.

Mechanical Construction Problems

After many years of experience, I believe the short-stroke engine is the best for all purposes when maximum high-speed torque is unessential. The last ounce of power at very high speeds involves a sacrifice of many other things for the sake of a compact combustion-chamber. Although justifiable in a high-speed racing engine, it will not be warranted in the automobile engine of commerce until high car speeds are much more important than at present. It must be remembered that while racing-car engine-speeds have increased some 50 per cent in the last few years, touring-car engine-speeds have remained stationary. Even now gear-ratios show signs of being increased, thus reducing the engine speed. The racing engine and the touring engine become more sharply differentiated year by year and, like race horses and racing yachts, racing cars are becoming a distinctly

separate breed with less than ever in common with the species from which they have sprung.

The cardinal points in the design of an engine for automobile use are:

(1) Light weight
(2) High brake thermal efficiency at light loads
(3) Low internal-friction losses

That the obsession of the long-stroke engine is passing is indicated by some of the later aircraft-engine designs such as the Napier Lion in which the bore is considerably greater than the stroke, this being a fair example of a large high-speed engine in which lightness is, of course, a sine qua non while high specific power and economy are essential. A large part of the weight of any engine is incurred through the geometrical disposition of its elements. For example, the necessity for maintaining a reasonable relation between the length of the connecting-rod and the crank in a long-stroke engine imposes upon the designer either a high crankcase or long cylinders whose only function, so to speak, is to fill up space. Further, the additional "crankiness" of a long-stroke crankshaft calls for more metal to maintain the desired stiffness. The short-stroke crankshaft is in this respect infinitely easier to deal with.

The argument for the inherent lightness of engines in which the bore and stroke are approximately equal is demonstrated easily by considering any standard design from the viewpoint of increasing the cylinder capacity thereof. It will be found that increase of bore will produce a corresponding increase of cylinder capacity with far less disturbance than that entailed by increasing the stroke. The only arguments against the short-stroke engine are that it is more difficult to obtain a compact combustion-chamber and to keep down piston temperature than with the same cylinder capacity but with a smaller bore. The aluminum piston can overcome the latter difficulty easily. My latest L-head engine of 4¼-in. bore and 4¼-in. stroke, having a compression-ratio of 4.5 to 1, is showing a brake fuel-consumption of 0.55 lb. per b.hp.-hr. at any speed from 600 to 2400 r.p.m. This is a figure that is by no means bad for any engine, regardless of its bore and stroke.

To obtain high brake thermal efficiency at light loads it is essential that the indicated thermal efficiency also shall be good; that is, that the direct cooling losses be reduced so far as possible and that the combustion-chamber be designed with the object of presenting the minimum surface per unit volume. At first sight, this seems inconsistent with ratios of bore to stroke that approach unity, but skilful design in placing the bulk of the compression space over the valves in an L-head engine will give results very comparable indeed with some of the best obtained in long-stroke overhead-valve engines. With this condition fulfilled, the question of reducing the internal friction-losses becomes of dominating importance.

The chief source of friction in automotive engines arises from the piston. Piston friction is about 50 per cent of the total friction in an automobile engine and obviously deserves attention as to whether it can be reduced. The whole question of internal losses has so far been the subject of more or less unsatisfactory guesswork, particularly in the statements on piston friction, and there is room for very valuable research work on this subject. My view is that piston friction is a function of inertia loading and oil-film shearing resistance, and that pistons showing a low friction-value are characterized by large clearances and small areas of contact between the piston and cylinder walls, or means whereby the oil-film can be "rolled up" without restriction. A familiar method of achieving the last is by the use of drilled pistons. Whatever the cause, the short-stroke engine seems to possess considerably less internal-friction than one of long stroke.

This does not seem unreasonable when it is borne in mind that the surface of the oil-film subjected to shear per stroke is a function of the circumference of the piston multiplied by the stroke, while the friction expressed in pounds per square inch of piston area is a function of the piston diameter squared, multiplied by the stroke. The optimum condition evidently is reached when the friction due to inertia loading, as such, plus that due to oil-film shearing, is a minimum. In this connection, due to exigencies of foundry work, the weight and hence the inertia loading produced by pistons of the sizes used in automobile engines do not increase according to the dimensional theory; that is, as the cube of similar dimensions, thus minimizing the inertia loading effect in the short-stroke engine compared with one of the same capacity but with a long stroke.

The essence of the mechanical aspect of engine design lies in this minimizing of inertia loading effects. From the familiar miles per gallon viewpoint it should never be forgotten that, taking for example a 3000-lb. automobile, it requires about 4 hp. to propel the vehicle at 20 m.p.h., while, at the engine speed corresponding with this car speed, a 180-cu. in. engine may easily absorb 2 hp. in mechanical friction alone. The results to be obtained by cutting down internal friction are thus indicated very clearly.

The use of materials of high specific-strength, so that the inertia loading is reduced, is important. Of such materials, the various alloys of aluminum possess unique properties owing to their low specific-gravity. The specific strength of a material is a number obtained by dividing the tensile-strength by the density, and it is interesting to note that from this viewpoint cast aluminum is equal to a 0.20-per cent-carbon forged steel, while forged aluminum has a value equal to that of some of the finest alloy-steels. Since the stresses induced in the piston and connecting-rod are very largely a function of the inertia of these parts, the importance of this consideration is evident. In addition, the reduction of such inertia stresses obviously reduces the inertia loading on the various engine bearings. They can either be reduced for equal life or have their life prolonged by such reduction of the inertia loading.

The virtues of the aluminum piston are now generally accepted from the viewpoints of lightness, heat conductivity and mechanical strength. Following upon this is the logical corollary of a forged aluminum connecting-rod. The loading on the connecting-rod big-end bearings is composed of (*a*) that due to the gaseous pressures arising during compression and expansion and (*b*) that due to inertia forces arising solely from the mass of the moving parts, namely, the piston and the connecting-rod. If the loading of the crankpin during a complete cycle be studied, the overwhelming importance of the inertia loading compared to that arising from the gaseous pressures will be manifest. In fact, it is invariably found that crankpin wear in high-speed engines occurs on the inner side of the crankpin; that is, that nearest the crank axis and not on the outer side of the crankpin, as would be the case if the wear due the pressures during explosion and compression predominated.

It is found that the use of an aluminum connecting-rod as against a steel connecting-rod, both having aluminum pistons, reduces the loading on the big-end bearings

by some 30 to 40 per cent, thus allowing the designer either to speed his engine up for a given bearing-endurance capacity or to increase the endurance capacity of the bearings in cases where these are already overloaded. In addition, the mass of the big-end of the connecting-rod plays no inconsiderable part in the torsional oscillations on long crankshafts, so that the use of an aluminum connecting-rod is entirely beneficial in engines where periods exist, arising from the above stated cause.

After considerable experience, I believe that the aluminum connecting-rod is one of the most important recent detail developments relating to internal-combustion-engine design. It is economical to manufacture and it is readily susceptible of being direct-babbitted, with all the advantages this method of construction carries with it. Now that the limiting factors of engine speed are being determined with something like precision, the importance of weight reduction in respect to rotating and reciprocating parts becomes more pronounced than ever. It seems highly probable that the use of aluminum for such parts will enable designers to reduce the bearing surface, thus cutting down the overall length of engines and making savings from the viewpoints of engine weight and cost of production that can be appreciated only after a careful investigation of the whole subject. In other words, the statement of a famous automobile engineer that "An ounce off the piston is as good as a hundredweight off the car" may be soon far more than an expression intended to emphasize the importance of weight reduction in respect to the rotating and reciprocating parts.

THE DISCUSSION

H. C. SNOW:—What should be the size of exhaust-valves?

L. H. POMEROY:—So far as exhaust-valves are concerned, the limiting diameter seems to be determined by cooling difficulties. I think it is not practicable to use an exhaust-valve of over 2-in. diameter on any engine running at more than 2000 r.p.m. It usually is possible to run with exhaust-valves that are very much smaller than the inlet-valves, without any loss of power or economy.

A MEMBER:—In connection with aluminum connecting-rods, have any alloys of aluminum been tried without using any babbitt metal in the bearings?

MR. POMEROY:—Several American firms have experimented with aluminum rods running directly on the crankshaft. In one instance a case-hardened crankshaft was used, but so far such experiments have not been successful and the recommended practice is to direct-babbitt the connecting-rod. There is, of course, no more objection to the use of babbitted bronze-shells than is the case with steel rods but, in view of the extra oil-film through which the heat generated by the friction of the bearing must pass, the use of babbitted bronze-shells deserves careful consideration as to whether the advantages they present in regard to replacements do not make the replacements necessary.

A MEMBER:—I understand that trouble has been experienced with the alloyed aluminum in making the babbitt metal adhere to it.

MR. POMEROY:—There is no more difficulty in successfully direct-babbitting an aluminum connecting-rod than in performing the same operation on a steel rod. In fact, it is considerably easier to make a firm union between babbitt and aluminum than between babbitt and steel.

A MEMBER:—You stated that the fuel-mixture is usually 15 to 1. What are the limits that can be used?

MR. POMEROY:—Under proper conditions of temperature and absence of deposition, the richest mixture that can be burned has about 10 parts of air to 1 of gasoline; the weakest mixture has about 20 parts of air to 1 of gasoline. In the richer mixture, combustion is not complete, but because the after-explosion volume of the mixture is greater than its volume before explosion, it will give an increase in mean effective pressure at the expense of economy.

A MEMBER:—What is the definite ratio of valve-lift to diameter of port? You referred to changing the diameter of the valves. It is easier to change the valve-lift in the ordinary engine than to change the diameter of the port.

MR. POMEROY:—All textbooks show that the lift of a valve should be one-fourth of its diameter, so that the area round the valve is the same as that of the port. This is, however, merely a geometrical equality and takes no account of the different orifice-coefficients arising from the fact that the gas is issuing through an annulus which is very different in shape from a circular port. The interesting experiments published in the Clarke-Thompson research[a] indicate that there is an increase in valve capacity up to a lift equal to 0.7 of the valve diameter and that the amount of gas that can be passed through a valve is proportional to its periphery multiplied by the lift. My own experience with two engines of which the valve area was in one case controlled by the height of the lift, keeping the valve diameter constant, and in the other case with varying valve diameters, keeping the lift constant, indicates the truth of this statement. Considering the compression-pressure at any given speed as a measure of the volumetric efficiency, the results obtained on these two engines were the same within 2 per cent, irrespective of the nature of the valve-opening. The difficulty in connection with the high valve-lift is to arrange for cam profiles and valve-springs to take care of it. The valve-spring seems to be the nearest metallurgical equivalent to dynamite and the difficulties in working with high speeds and high valve-lifts can be thoroughly appreciated only after bitter experience.

A MEMBER:—What is the general tendency of internal-combustion-engine speeds in Europe? Has there been any increase in them?

MR. POMEROY:—The only alteration in engine speeds in European practice is that due to reductions of gear-ratios, thus increasing the average speed of the engine. On the other hand, the maximum speed has not been altered greatly except in some of the new sport-type cars where high car speeds on indirect gears are desired. Possibly the most interesting developments in this respect occur with the so-called light cars that have engines capable of maintaining speeds of 2500 to 3500 r.p.m. for hours on end.

A MEMBER:—In regard to your experiments with the reduced inlet-valve, how much value do you attribute to turbulence in the results obtained?

MR. POMEROY:—Turbulence is a function of gas velocity. On the other hand, it seems rational to consider not only gas velocity but gas velocity and revolution speed as being correlated. It is obvious that a gas velocity of 100 ft. per sec. will give all the necessary turbulence for complete ignition at 500 r.p.m., but be entirely inadequate at 2500 r.p.m. The relationship between gas velocity and revolution speed is of great interest, although I am strongly of the opinion that it is possible to use higher

[a] See National Advisory Committee for Aeronautics Report No. 24.

(*Concluded on p.* 354)

Notes on Motor Trucks

By Cornelius T. Myers[1]

Pennsylvania Section Paper *Illustrated with* Photographs and Charts

After pointing out that the publication of articles in the trade and technical journals, to the effect that very considerable weight-reductions in motor-truck construction with consequent savings in gasoline and tires are possible, works an injustice to the motor-truck industry and is misleading, the author outlines some of the reasons why such weight-reductions are very difficult to effect, as well as the possibilities of standardizing axle details. The use of aluminum to effect weight-reduction is commented upon and the various advantages claimed for metal wheels are mentioned. In the latter connection the author points out that, while these claims may be true, they are unsupported by reliable data.

The greater part of the paper is devoted to an account of a series of tests conducted by a large coal company to determine the relative merits of wood and metal wheels on its trucks. Four trucks, each equipped with wood and metal wheels on diagonal corners so as to secure, as far as possible, an equalization of conditions were employed. The tests lasted over a year, and at their conclusion it was found that the average wear of the tires mounted on metal wheels was about 13 per cent greater than that of those mounted on wood wheels.

The question of unsprung weight is discussed, as is the importance of reducing chassis and body weights to a minimum, but it is pointed out that a reduction in these weights does not necessarily mean a resultant saving in the gasoline consumption or the tire expense. Lubrication of the various parts of a motor-truck chassis also receives attention, the annual cost of truck repairs due to poor lubrication of the chassis being given as from $15,000,000 to $20,000,000, in addition to which there is a loss of earnings while the trucks are being repaired of from $30,000,000 to $35,000,000. The superiority of oil over grease as a chassis lubricant is emphasized.

In conclusion it is pointed out that the next few years will see bitter competition in motor-truck service and that refinement of detail and simplification of operating features will be emphasized. The need for the unexperienced buyer to secure expert advice regarding the design of the vehicles offered him is stressed, it being stated that this practice would clarify the situation for both the buyer and the seller.

Articles keep appearing from time to time in various publications to the effect that our motor trucks are far too heavy and that they can be lightened materially if we but use aluminum and alloy-steels in this or that form; also that these weight-reductions will effect big savings in gasoline and tires. These articles prophesy a Ford passenger-car descendent in a motor truck, and are not at all just to the motor-truck industry in that they lead purchasers to believe that the near future holds out the fulfillment of such a promise. There are also statements in regard to unsprung weight, quantity production, wheel construction and similar subjects that are likely to be misleading to those not in close touch with the subject. Doubtless, in time, great advances in construction will be achieved, but this will be rather by a large number of short steps than by a revolutionary change in design.

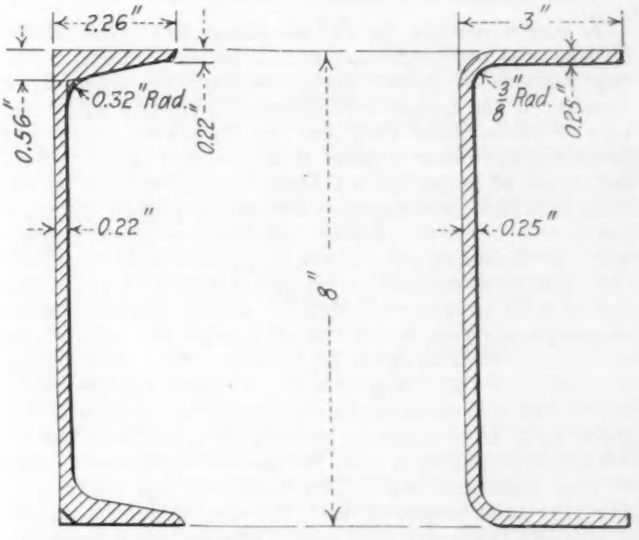

Fig. 1—Rolled and Pressed Steel Frame Sections

The Standard Rolled Channel Is 1 Per Cent Lighter and 7 Per Cent Stiffer Than the Pressed Channel. The Latter Permits the Use of Large and Easily Made Fillets in the Frame Bracket, Although the Rolled Section Is Often Beveled Off to Give the Same Advantage. Bolts Through the Flanges of the Rolled Channel Require Special Wedge-Shaped Washers to Hold the Heads True

We often hear the alloy-steel man talk of much lighter frame-sections, etc., but we have reached a point today in motor-truck construction where the possibilities for chassis weight-reduction are approaching a safe limit, regardless of application of higher-grade steels, because the limiting features in many parts of the chassis design are those of deflection and of metal thickness sufficient to hold rivets and avoid buckling, rather than tensile stress. One magazine article states, "In frame construction the old heavy charcoal-iron has been almost entirely superseded by the pressed steel which, with about half the weight of the former, possesses nearly double its strength." This would result in making each pound of steel in the frame about four times more effective. But this is not the case. Presuming that "charcoal iron" refers to the rolled standard structural section, it is worthy of note that several very widely known and highly rated truck builders still use frame steel in this form, and also that their frame weights are, if anything, heavier today than 8 or 10 years ago for similar load capacities. Further, the weight of frames made of pressed steel for similar load capacities by well-established competing truck builders averages about the same as the weight of frames made from rolled sections as is brought out in Fig. 1.

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The same principle applies to axles. Lighter front-axles can be made of high-tensile heat-treated steel, but under working loads the deflections would be such as to seriously misalign the wheel spindles and steering connections. Also, such an axle, when accidentally bent could be straightened only with difficulty and would have doubtful value thereafter as a load carrier. Rear axles, too, could be lightened in the same way, but at the expense of misalignment under load deflections that would be fatal to their driving mechanisms.

Possibilities in Rear-Axle Standardization

A comprehensive paper on Rear Axles for Motor Trucks was presented last month before the Metropolitan Section. A casual glance through the paper by a member of the Society's Standards Committee will cause him to contemplate with awe the enormous investment in axle spare parts it must entail to service the different makes of motor truck already in operation. Further contemplation increases this by the amount of different manufacturing tool equipment necessary to produce them, and the terrific expense it must entail to keep the many little armies of salesmen each fighting their twenty-sided battles over unimportant detail. Eighty million dollars is spent every year to sell trucks, a large part of it going to support fruitless detail arguments. The truck industry now generally recognizes that it must sell transportation and not details, and there seems to be a great opportunity to standardize on axle details. Everyone at interest will benefit by this, for all the well-known types of rear axle are firmly established in the trade and give very good results in use. The user is not interested in axles if they carry his goods without disturbing his peace of mind. When accidents happen or wear takes place, however, he wants repairs made quickly and cheaply. This not only saves him money but keeps him in the frame of mind to spend money in buying another truck. I will put before you certain features of the various axle designs that seem to offer more or less attractive fields in which to pursue the well-defined and enormously profitable policy of standardization, that has been steadfastly fostered by the Society of Automotive Engineers.

(1) For each of seven truck sizes, standard spring center-lines and spring widths can be established; giving a reasonable variation, for the time being, by using spring-pads that are wider than necessary. The spring centers will depend on frame widths, a subject that is already being attacked with every reason to expect success. These established, the spring clips and nuts will fall readily in line. Even the spring-pad drilling and spring-seat height offer possibilities of being reconciled between chain-drive and internal-gear axles, and also among single-reduction, double-reduction and worm-drive axles

(2) Standard brake-drum diameters, widths and metal thicknesses are now being discussed in the Standards Committee and tentative dimensions have been suggested. Once these are determined, the door will be open to the crying need for standardizing the dimensions of brake-linings, rivets, hinge pins, cams or toggles, diameters of camshafts and bushings, fits for camshaft levers, clearances and movements, release springs and all the minor details that are so annoying when replacements are needed at an inopportune time or in an out-of-the-way place. There will be double paths to follow here by those who differ as to having more than one brake inside the drum, and also by the adherents of the external brake

(3) Once the brake-drum width is selected, the wheel spoke is located. The wood wheel can fall in line readily here and the steel wheel also. Our tire sizes are standard and also their fits on the wheels. Standard practice with reference to front-wheel hubs has already been adopted. The rear hubs also should yield to the same analysis and attack, though the solution will not be so simple. The hub details depend upon the type, size and location of the bearings used

(4) The wheel bearings cause a considerable diversification. Either ball or roller bearings can be employed in each of the five types of axle most used. But of these five types single-reduction, double-reduction and worm-drive can be grouped in both the fixed-hub or full-floating designs; while chain-drive and internal-gear drive also can be grouped. Thus, for each size truck axle 16 variations in bearing sizes, types, fits and spacing may be reduced to six. Possibly a thorough study of the situation would reduce these still further, as was found possible in the front-hub bearing standardization, in which over 200 hub variations were boiled down to 10, which are served by only 14 bearings

(5) Fits for hubs, flanges, hub-caps and wheels can be standardized correspondingly, once the bearings are fixed

(6) The fits at the outer ends of spindles and drive-shafts can be standardized in accordance with the classification given under (4); and if the wheel tracks are held close the spindles and drive-shafts themselves offer possibilities. Items 4, 5 and 6 will react on the spring-pads mentioned under (1), and help reconcile some discrepancies that at first may occur there

(7) Differentials can be standardized. The subject is now under consideration. A reasonable number of sizes to cover the range of torques to be transmitted, is all that is necessary. It should make little difference in what type of axle they are used. There would be a series for ball bearings and a series for roller bearings.

(8) The above accomplished, the fits for the inner ends of drive-shafts would fall in line.

(9) Bevel, spur and worm gears all offer great opportunities for standardization. This would lead to a similar accomplishment for the bearings and bearing fits on worm spindles and bevel-pinion spindles, but these can be standardized whether or not the gearing is standardized

(10) Adjusting devices for differential bearings and spindle bearings also offer a field

(11) The spindle fits for universal-joint flanges have already been standardized

(12) Clevises and pins for brake-lever connections have been standardized. Possibly the levers themselves are susceptible to this work

Here, then, are 12 features in rear-axle standardization, some of them having been solved. All types of rear axle are now so perfected and perform so well that a standardization of all assembly dimensions and common details is the next big move in the progress of the industry.

Alloy-steel crankshafts are negligibly lighter for the same stiffness than those made of less expensive carbon-steel. The alloy-steel will resist wear somewhat better than carbon-steel if the latter is not case-hardened. However, wear can best be reduced by improved lubrication.

Weight-reduction by means of aluminum is not new in engine crankcases, gearboxes, radiators and other smaller parts. Temporarily, cast iron is being used to a large

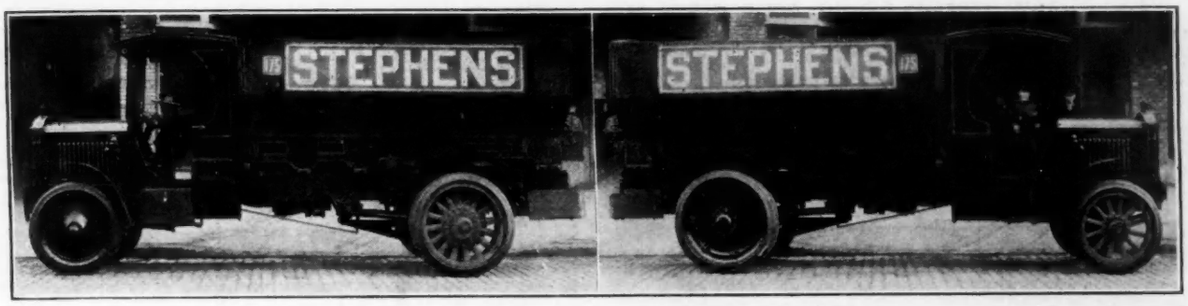

FIG. 2—VIEWS OF OPPOSITE SIDES OF ONE OF THE TRUCKS TESTED

extent, because of the high cost of aluminum. Aluminum has been used successfully in some parts of passenger-car rear-axles. Some experimental truck-axles have been made of it. But this metal has a structure too coarsely crystalline to make it readily serviceable under the heavy and uncushioned shock loads a truck rear-axle must endure. Some alloy of aluminum may solve the problem, however.

A few truck wheels have been made of aluminum but with unsatisfactory results. The most promising truck wheel today is the wood-spoke type but of lighter construction and better detail than those made in the past. There is much misunderstanding of the functions performed by motor-vehicle wheels, and much misinformation has been circulated in the past few years. The average man's idea of a wheel covers a device that revolves on an axle spindle and carries a tire. The common opinion is that the stronger a wheel is, the better. This accounts to a considerable extent for the development of various types of metal wheels, cast steel, malleable cast iron, rolled or pressed disc and even forged steel, that are offered and championed mainly on two contentions that (*a*) they are stronger than the wood-spoked wheel; and (*b*) they are more accurately made and more true than the wood-spoked wheel. Both of these contentions are true. It is claimed, therefore, that

(1) Tires mounted on them will last longer
(2) Gasoline consumption will be less
(3) The truck will be less liable to be put out of commission due to accidental damage to the wheels

It is claimed also that cast-metal wheels weigh less than the conventional wood wheel and therefore decrease the unsprung weight, 1 lb. of unsprung weight being variously estimated in these claims as equivalent in load effect to 5 to 10 lb. of weight above the springs.

WOOD AND METAL WHEELS

For several years there has been considerable controversy as to the relative merits of motor-truck wheels made of wood in the usual manner and those made of cast steel or malleable iron. The following are typical statements, taken from manufacturers' circulars or from the advertising pages of trade papers with reference to cast-metal wheels:

> The permanent true roundness of .... wheels makes for lower fuel bills, and increases the mileage obtained from tires. Users tell us of increases of from 10 to 30 per cent
>
> They increase tire life; they decrease fuel consumption
>
> To move a pound of weight in the wheels requires as great an expenditure of tires, power and fuel as is needed to move 10 lb. above the springs..... ..... wheels are as much as 100 lb. lighter per set than other types of wheels
>
> Their trueness and roundness add 10 to 25 per cent to the mileage obtainable from tires
>
> They reduce unsprung weight and lower tire costs

Repeated inquiry among those who made these statements convinced me that they were made on a basis of supposition and hope, and not on established data. Possibly the claims were true, but no data supporting them were forthcoming. Neither was there any sound basis for the statements made in regard to unsprung weight, or the inferences drawn therefrom.

While it is true that the manufacturing limits for roundness of wood wheels are several times as great as those for steel wheels, the variations allowed the wood-wheel manufacturer are so small as to be negligible in the operation of the truck. The inequalities of the road surface are so much greater and the cushioning value of the tire is so large that the effect of the relatively minute wheel variations cannot be measured in any operating expense. The greater accuracy of the metal wheel seems, therefore, to be but gilt on the lily.

In checking up wheel weights it was found that in commercial production the cast wheels were in most cases heavier than wood wheels built for the same load capacity, especially in sizes up to those suitable for 3½-ton trucks. In sizes for 5 to 7½-ton trucks wheel weights in some instances more nearly coincided but the wood wheels still averaged somewhat less in weight. In comparing weights the weight of the hub, flange and brake-drum or sprocket assemblies were included in the weight of the wheels. It did not seem likely that the heavier metal wheels would give greater tire mileage; but our absolute knowledge of the effects of varying amounts and proportions of sprung and unsprung weight is still very limited. In spite of the fact that the superior tire-mileage claims were based on *lighter weights* for metal wheels, it seemed that some comparative data should be secured, rather than leave the truck user to conjecture on a point so important in the operation of his vehicles. The motor-truck user has to spend his good money for everything he gets, and it is important for him to know whether the extra price he has to pay for cast wheels really comes back to him in tire savings. A practical test under every-day conditions, but with proper safeguards, is necessary to secure this information.

TESTS MADE WITH FOUR TRUCKS

A company that trucked large tonnages of coal in one of our big cities, was interested in this subject, equipped four of its trucks and conducted such a trial. It operates a large fleet of trucks, mostly of 6½ and 7-ton capacity. It keeps a careful record system that includes mileage, tonnage and operating costs. Its trucks are well kept-up. The drivers are well trained. The operation of the trucks is very capably supervised. Altogether the conditions were as near ideal as could be expected.

On trucks of 5-ton capacity and up, wood wheels are thought to be at more of a disadvantage than on trucks of smaller capacity, and 6½ and 7-ton trucks were therefore used in the test. The trucks carried full loads on each trip and operated on regular schedules and predetermined routes. Half of the trucks were equipped with

TABLE 1—WHEEL AND TIRE EQUIPMENT

Truck No.	Front		Back	
	Wood	Metal	Wood	Metal
162	*Left*	*Right*	*Right*	*Left*
	Interlock spoke	Hollow spoke	Interlock spoke	Hollow spoke
	36 x 6 S	36 x 6 S	40 x 6 D	40 x 6 D
168	*Right*	*Left*	*Left*	*Right*
	Mitred spoke	Hollow spoke	Interlock spoke	Hollow spoke
	36 x 6 S	36 x 6 S	40 x 6 D	40 x 6 D
172	*Left*	*Right*	*Right*	*Left*
	Mitred spoke	Cast disc	Mitred spoke	Cast disc
	36 x 6 S	36 x 6 S	40 x 7 D	40 x 7 D
175	*Right*	*Left*	*Left*	*Right*
	Mitred spoke	Cast disc	Mitred spoke	Cast disc
	36 x 6 S	36 x 6 S	40 x 7 D	40 x 7 D

wood wheels on the right-hand end of the front axle and the left-hand end of the rear axle; the wheels at the other diagonal corners of the truck being cast-metal as is shown in Fig. 2. All the wheels were equipped with new tires, of not only the same make, but made at about the same time with the same compound and cure. All tires contained approximately the same thickness of rubber. The rated loads on the tires were within commercial limits of good practice per inch of width, and these loads did not vary widely for the different trucks used.

Two chain-drive trucks, Nos. 162 and 168, and two worm-drive trucks, Nos. 172 and 175, were selected for the test. The wheel equipment was as set forth in Table 1.

Each wheel was carefully stamped for identification. The metal wheels for trucks Nos. 162 and 168 and the wood wheels for trucks Nos. 172 and 175 were new, but

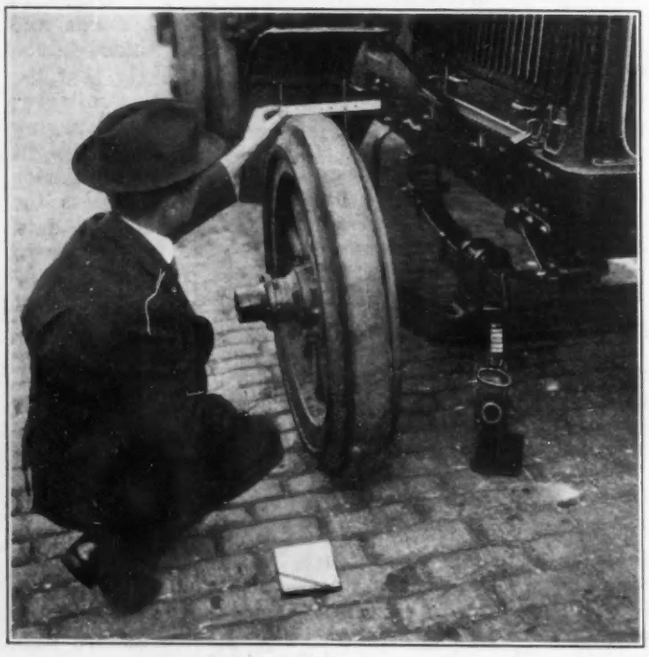

FIG. 3—TAKING MEASUREMENTS OF THE HEIGHT OF THE RUBBER ABOVE THE TIRE BAND

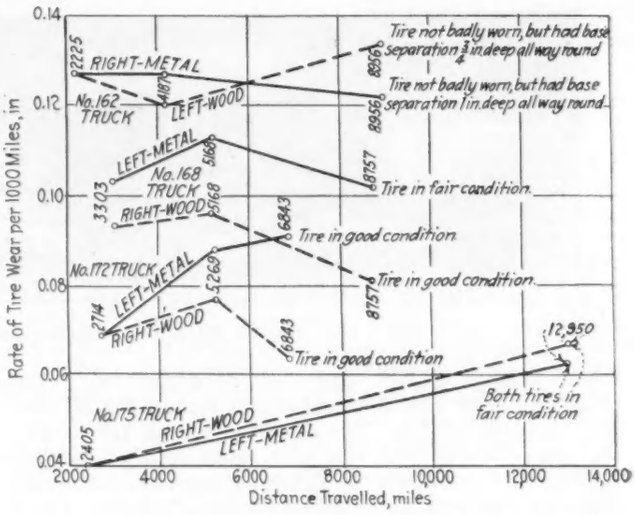

FIG. 4—RELATION BETWEEN THE RATE OF TIRE WEAR PER 1000 MILES OF TRAVEL AND THE DISTANCE COVERED FOR FRONT WHEELS

the wood wheels, for trucks Nos. 162 and 168 and the metal wheels for trucks Nos. 172 and 175 had had considerable service on these trucks. This arrangement, it will be noted, placed the wood wheels and also the metal wheels at diagonal corners of each truck, but alternated them as to rights and lefts on the two trucks of the same make. This assured that the average wear would take place under the same conditions for both wood and metal wheels. The superintendent said that his records showed that in general the tires on the right-hand side of their trucks wore-out somewhat more rapidly than those on the left-hand side. This is probably due to the slight slope of the road toward the right, which loads the tires on the right-hand side somewhat more than those on the left-hand side.

The front wheels on all four trucks carried 36 x 6-in. single tires. The back wheels on trucks Nos. 162 and 168 carried 40 x 6-in. dual tires, while the back wheels on trucks Nos. 172 and 175 carried 40 x 7-in. dual tires; 24 tires in all being included in the test so as to get a fair average.

Before purchasing the tires the matter of furnishing a uniform quality was taken up in detail with the tire factory, and after careful inquiry tires were selected that had all been produced at about the same time, and which the factory stated could be depended upon to be practically uniform and give comparable results in this test.

Each steel tire-band was stamped for identification so that damage to the serial number on the tire would not cause confusion. Each tire-band was then marked at six places, equidistant around the rim. At each of these places the height of the rubber above the flange of the band was measured carefully with a gage made especially for that purpose as shown in Fig. 3. The average of these measurements was taken as the initial height of the rubber in the tire. All measurements were checked by two persons. Tires selected were applied at random on the wheels, and it was impossible to distinguish any difference in them.

As each truck was equipped with new tires, records of mileage and tonnage were carefully compiled. The starting dates of the tests are given in Table 2.

In addition to the regular operating records of these trucks (they were operated entirely in accordance with the business demands and not given any special routes or service) the tires were given a special inspection about

TABLE 2—STARTING DATES OF TESTS

Truck No.	
162	Nov. 11, 1920
168	Nov. 12, 1920
172	Nov. 19, 1920
175	Nov. 18, 1920

once a month. This was to keep track of any unusual wear, bad cuts, base separation, etc.

Due to the mild winter of 1920-1921 these coal trucks did not cover a very great mileage for the first month or so. Each load carried, however, was a capacity load, as can be seen from Table 3.

TABLE 3—CAPACITY AND LOAD PER INCH OF TIRE WIDTH

Truck No.	Pay-Load Capacity, tons	Average Weight per Inch of Tire Width, lb.
162	6½	720
168	6½	743
172	7	702
175	7	696

On March 4, 1921, inspection of the tires showed but little wear, and all of them were in good condition. Measurements were taken. The rates of wear in inches per 1000 miles and the mileage at that date are shown on

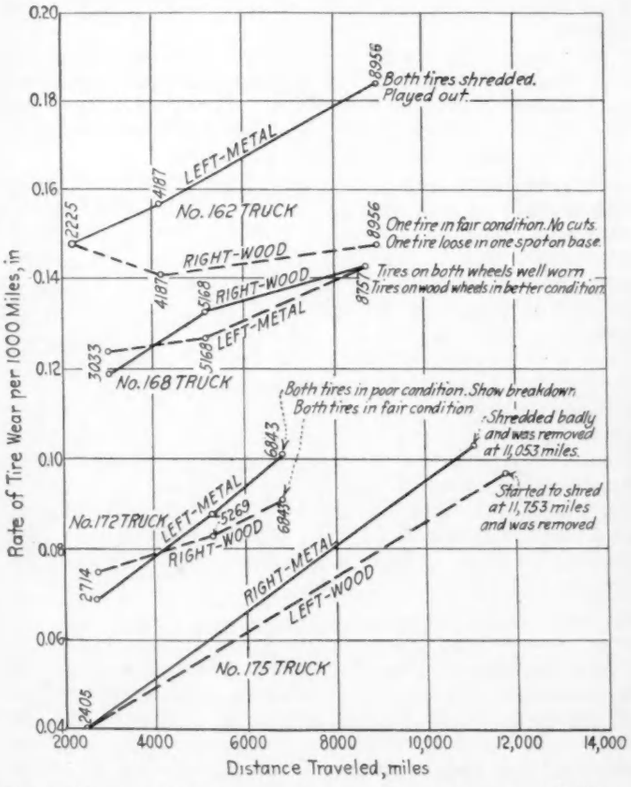

FIG. 5—RELATION BETWEEN THE RATE OF TIRE WEAR PER 1000 MILES OF TRAVEL AND THE DISTANCE COVERED FOR REAR WHEELS

charts reproduced in Figs. 4 and 5. The average rates of wear show that for the front wheels the tires on the wood wheels were doing about 2.75 per cent better than those on the steel wheels. On the rear wheels the tires on the steel wheels averaged 0.5 per cent better than those on the wood wheels.

In considering the results given herein, it must be borne in mind that the differences in rate of wear between individual trucks is not directly comparable, because they all operated under somewhat different conditions. For instance,

(1) Their routes and mileage varied

(2) Their tare-weights were different, as is indicated

FIG. 6—REAR WOOD WHEEL ON THE SAME AXLE AS THE WHEEL IN FIG. 7 AND ITS TIRE AT THE CONCLUSION OF THE TEST

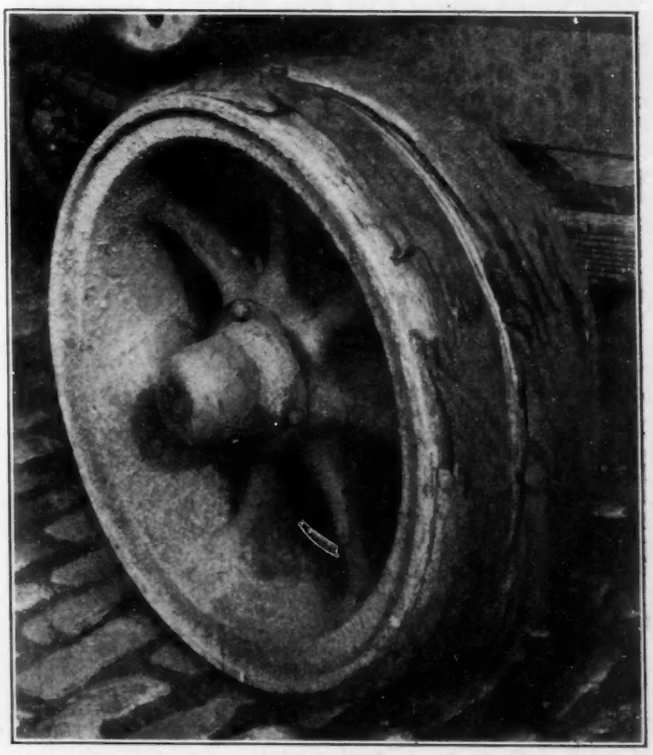

FIG. 7—REAR METAL WHEEL ON THE SAME AXLE AS THE WHEEL IN FIG. 6 AND ITS TIRE AT THE CONCLUSION OF THE TEST

by the weights per inch of tire width given in Table 3

(3) They had different drivers; often an important item
(4) The size of the back tires was different
(5) The load per inch of tire width varied
(6) They operated at different average speeds, though at the same maximum speed
(7) The springs of the chain-drive trucks were not the same as those on the worm-drive trucks

To compare, therefore, the results in tire wear of trucks Nos. 162 and 168 with those of trucks Nos. 172 and 175 is misleading on account of the variables. True comparisons are possible only where all essential conditions are the same. It was realized that this difficulty would confront any attempts to get the comparisons in tire service on wood and on cast metal wheels; hence the use of four different trucks and the alternate diagonal arrangement of the wheels. Here the average results are an indication of the relative service, because both front tires and both sets of rear tires on each truck were subjected to the same operating conditions, with the exception that possibly the tires on one side of each truck might have slightly more load to carry than those on the other side. To counter this exception the "hand" of the wheels was alternated on similar trucks; wood wheels being placed on the right-hand end of the front axle on one chain-drive and one worm-drive truck, but on the left-hand end of the front axle for the other chain-drive and worm-drive. This arrangement was followed also on the rear axles, as will be seen by referring to Table 1.

During the next 10 or 11 weeks the trucks were in active service, and on May 20 another series of tire measurements was taken. The inspection showed that all the tires seemed to be wearing uniformly. There were no large cuts, no hangnails, and no base-separations. Even from a casual glance, however, the tires on some of the metal wheels showed more wear than those on the wood wheels on the same truck. Figs. 4 and 5 give the individual rates of wear and mileages up to May 20.

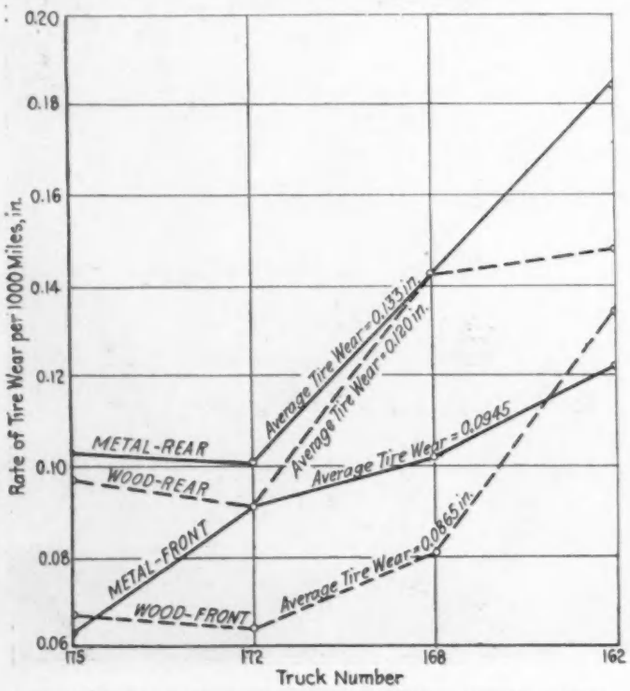

FIG. 8—RELATIVE RATES OF WEAR OF FRONT AND REAR TIRES MOUNTED ON METAL AND WOOD WHEELS PER 1000 MILES

Through the late summer and early fall there was comparatively little for these trucks to do, and it was not until some of the rear tires showed signs of disintegration that the next measurements were taken, on Dec. 1, 1921, a little over a year from the time the tires were new and first measured. These measurements showed that for the eight front tires the average wear of those mounted on metal wheels was 9 per cent greater than the wear on the tires mounted on wood wheels; also that for the 16 back tires the wear of those mounted on metal wheels was nearly 11 per cent greater than the wear of the tires mounted on wood wheels. These percentages are based on the average rates of wear per 1000 miles over the entire period. The charts show the cumulative results at the end of each period when measurements were taken.

Of the tires on rear metal wheels none exceeded the tires on the rear wood wheels in mileage. On truck No. 168 they were equal, but on the other three trucks the tires on the wood wheels gave superior results. Not only were the tires worn more on the metal wheels but they showed signs of disintegration to a much greater extent than those on the wood wheels. Late in the fall of 1921 the superintendent in charge of the operation of trucks, who had previously thought the metal wheels were the more desirable, stated that there was no use taking any more measurements, for anybody could see that the tires on the wood wheels were giving better service.

On the front wheels none of the tires had worn-out, but those on truck No. 162 showed that base separation had started. On the back wheels all the tires were well worn; some of them were shredded and about to be replaced, as can be seen from Figs. 6 and 7.

As the tires wore down and their cushioning effect diminished, it was noticeable that small failure cracks appeared sooner and developed into larger cracks in almost every case in the tires on the metal wheels. As the steel wheels in every case exceeded the wood wheels in weight it might be thought that this was due to the greater inertia of the heavier wheels. This may have been true to some extent, and it appears reasonable but, if that was the case, how can the differences in the tire mileage between the chain-drive trucks and the worm-drive trucks be explained? The worm-drive trucks gave the better results and the unsprung weight of their axles considerably exceeded that of the chain-drive. Neglecting wheels and tires the weight of the worm-drive rear-axle parts was about 1400 lb. greater than that of the chain-drive axle. These results need careful interpretation as will be indicated later.

UNSPRUNG WEIGHT

It is my opinion that the relative effect of a difference in unsprung weight is modified to a considerable extent by the presence of the springs above the axle and, of course, the speed at which the truck operates, as well as the thickness and hardness of the tire itself. In other words, against vertical impact there is the cushioning effect of the springs, and to some extent of the frame and load itself, as well as of the tire. The tire therefore does not have to withstand the full force of the road impact when delivered in a vertical plane. When the blow is delivered in a horizontal plane, however, the springs are not able to cushion the blow and the tire must absorb the full impact if the wheel is rigid. Neither is the tire designed to withstand sidewise or skid loads as efficiently as the vertical loads.

One of the important functions of a wheel is the abil-

ity to act to some extent as a cushion to the savage side-thrusts of rut and curb. The wood wheel is several times as resilient as the metal wheel and affords this protection, while the metal wheel does not flex to any appreciable extent. Thus with wood wheels the tire has some assistance from the resilient spoke at the time it needs it most. In the extreme case of a heavy side-skid against a curb, the wood wheel breaks, acting like the fuse in an overloaded electric circuit, and protecting more expensive parts.

Tire Wear Per Thousand Miles

Figs. 4 and 5 show the results of the test in terms of mileage and rate of wear per 1000 miles. As the results for the different trucks vary so much, it may be thought that the test was not a fair one because the individual tires themselves must have varied in composition. In this connection it should be noted that the rates of wear

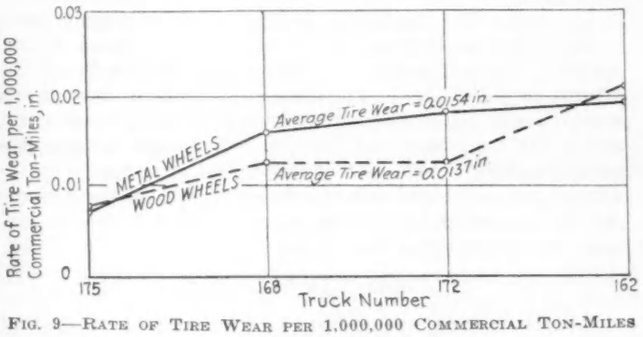

Fig. 9—Rate of Tire Wear per 1,000,000 Commercial Ton-Miles for Front Tires

of the tires of each truck form a distinct group. The differences in the rates of wear, therefore, are not due to differences in tires, but to differences in trucks, their drivers or operating conditions. Figs. 4 and 5 show this plainly. Fig. 8 shows the rates of wear per 1000 miles on the front and rear tires, plotted to show the relative difference between the tires on the wood and the metal wheels.

Figs. 9 and 10 show the rates of tire wear per 1,000,000 commercial ton-miles. Here we see that trucks Nos. 168 and 172 are not very far apart in tire wear when certain allowances are made. The front tires on truck No. 168 show 7 per cent less wear than those on No. 172. The rear tires on truck No. 172 show 15 per cent less wear than those on No. 168. It should be noted, however, that truck No. 172 had the advantage of 4 in. more in width of tire on the two rear wheels, which probably accounts for a great part of this difference. On the basis of commercial ton-miles we find that for the front wheels the rate of wear was about 12½ per cent greater for the tires mounted on metal wheels, while at the rear the rate of wear was about 13 per cent greater for the tires mounted on metal wheels.

Truck No. 175 was in charge of a very careful driver and in every way was kept in as nearly 100 per cent of first-class condition as was possible. During the last few months of the test this truck was hired out to some contractors, as not enough coal was being delivered to keep it in that service. On this contract work it covered greater distances than on the coal deliveries, and making extra trips it rolled up a big commercial ton-mileage. This is a case of exceptionally good performance by a carefully groomed truck, and a very good driver.

Fig. 11 gives a final comparison between the rates of wear per 1,000,000 commercial ton-miles of tires on wood

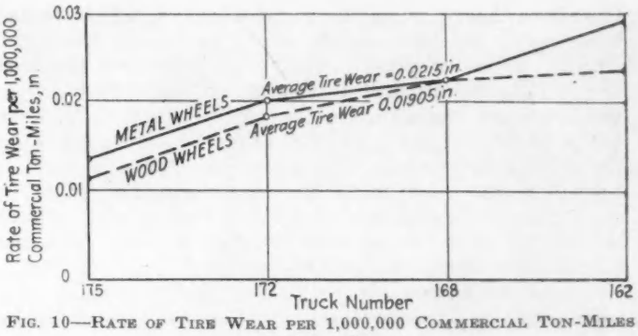

Fig. 10—Rate of Tire Wear per 1,000,000 Commercial Ton-Miles for Rear Tires

and metal wheels. It averages the rates of wear of the six tires on each truck, or 24 tires in all. Twelve of these were on wood wheels and 12 on metal wheels.

In setting forth the results of this test it is not intended to convey the impression that solid tires on wood wheels will give uniformly from 10 to 15 per cent better performances than on metal wheels. The number of trucks tested was far too small to justify such a conclusion. The results are strongly indicative, however, and cast grave doubts on the unsupported statements of those who have sold us steel wheels. It seems safe to say that the claims for metal wheels, cited early in this report, are by no means justified. Those who make such claims should demonstrate them beyond doubt by concrete performance.

The logic of lighter and more resilient wheels would indicate a better performance by the wood wheels, even in the event of no great amount of confirmative data. The claim for better performance by a metal wheel because it is more nearly round and true is really a point of minor importance, because the road inequalities so vastly exceed the very small variations that occur in a well-made wood wheel that even a worn tire will practically nullify them.

It has been claimed also on many occasions that solid tires wear less on metal wheels than on wood wheels, because the former "radiate" the heat generated in the tire at a more rapid rate than the latter. This is another theory that has not by any means been established. The test described above shows that the difference in the rate of wear was greatest in favor of the tires on the wood wheels during the heat of summer, directly contrary to

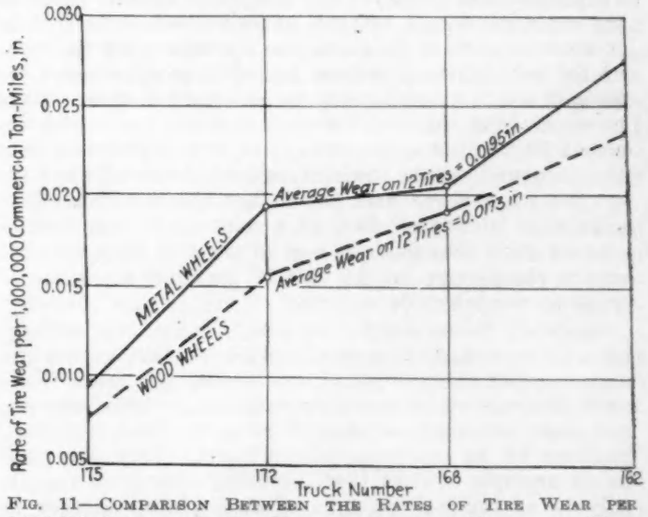

Fig. 11—Comparison Between the Rates of Tire Wear per 1,000,000 Commercial Ton-Miles of Tires on Metal and Wood Wheels

the above theory, when the metal wheels should have had the greater relative cooling effect and saved the tires. The theory is defective in that it assumes that the heat due to the rolling of the tire causes more rapid wear, and that the radiating factor of the wheel is a large factor in cooling the tire. However, the air surrounding the rubber is probably of major importance in cooling the tire; and if the metal wheels are painted, as is almost universally the case, the paint film probably offsets the ability of the metal itself to transfer heat from the tire-band to the air around the spokes.

It is true that during 1917, 1918 and 1919 some very poor wood wheels were produced and assembled under trucks, and these have been held up as horrible examples. These were produced under extenuating conditions, and are by no means typical of the millions produced prior to that time and still giving good service if they have had reasonable care.

In regard to weights, the cast-metal wheel is seldom as light as the ordinary wood wheel, which is really heavier now than it need be. This item also touches on the much bandied question of the relative importance of unsprung weight to the total load carried. This is most often cited in discussions of different types of rear axle. It is reasonable to suppose that the lighter the axle the less will be the force of the blow transmitted through the springs to the frame when the wheels encounter bumps in the road surface. The relative effect of heavier blows by heavier axles is not readily discernible on the load carried, however, if the truck has well-designed springs, especially if these springs are well lubricated. Then, too, the heavier the axle the greater the proportion of the blow absorbed in the tire, due to the greater inertia of the axle. So, it would seem that this would be accompanied by a greater tire wear under the heavier axle. But again there are no reliable supporting data.

Of the four trucks used by the coal dealer in the tire-mileage test already mentioned, two had worm-drive rear-axles, the heaviest type, and two had chain-drive rear-axles, the lightest type. The rear-axle loads per inch of tire width were about 7 per cent greater for the chain drive than for the worm drive. Leaving out all reference to unsprung weights, one would expect the tires on the chain-drive trucks to show somewhat more wear, perhaps 10 per cent, per commercial ton-mile. The total weight of the worm-drive axle, wheels, tires, etc., was 70 per cent in excess of the weight of similar parts on the chain-drive axle. If 1 lb. of weight below the springs is equivalent to 5 lb. above the springs, then the tires on the worm-drive axle were loaded 31 per cent more per inch of width than those on the chain-drive axle. If the more fanciful ratio of 10 to 1 is used, the excess becomes 68 per cent. In any event, if the proponents of the unsprung weight theories are to be believed, the tires on the worm-drive axle should get the worst of it to a substantial degree, but, as a matter of fact, careful records show that average rate of wear of the rear tires on the chain-drive trucks was 53 per cent in excess of those on the worm-drive trucks.

Certainly these results do not indicate that a light axle saves tires. However, neither do they prove the opposite, because the conditions of the test were made such as to afford comparative data on the wheel service, and were *not* such as to enable one to draw fair comparisons on an unsprung-weight basis. They are cited as an example of data that are being submitted repeatedly in advocating one type of design over another in making truck sales, and buyers should be on guard against such statistics and comparisons.

Nothing in this paper should be construed as deprecating the importance of reducing chassis and body weights to a minimum. For every idle pound of such weight removed, a pound of useful load can be added. Weight-reduction, however, does not always mean a proportionate gasoline or tire saving. Other factors enter into these items of expense, and those who generalize expose themselves to the same error as those who have allowed their imaginations to over-emphasize the importance of a minimum unsprung-weight. To date there are no data on which to make safe comparisons, and a full exposition of the subject may establish a different feeling than that which exists at present.

Engine weights can be reduced if improvements in fuel and lubrication allow us to use higher compressions and maintain oil-films on rubbing surfaces. The air-cooled engine will effect a considerable weight-reduction if perfected for motor-truck service, and this is not at all impossible.

For years the intensive study given to the main units of the chassis, engine, radiator, gearbox, axles, frame, springs, steering-gear, etc., has absorbed nearly all the efforts of designers. The details by which these units were assembled in the chassis, kept in proper relation, and controlled, have suffered by comparison. As a consequence they have been responsible for many breakdowns and a heavy upkeep expense. At present these details are receiving closer attention but there is still room for improvement.

Chassis Lubrication

An outstanding subject at the present time is that of chassis lubrication, the lubrication of the numerous small pins and bearings connecting the working units of the chassis. All mechanical motion, in the millions of forms that surround us on every hand, depends upon good lubrication for its continued existence. The lubrication of steering pivots and connections, universal-joints, spring-bolts, pedal-shafts, brake-shafts, radius-rod pins, clutch-release bearings, unit support pivots, etc., of motor trucks, in most cases has been cared for crudely in the chassis design. Consequently these parts have been subject to severe wear and entailed heavy upkeep expense. Lack of good lubrication in engines, gearboxes or rear axles is quickly attended with an ominous noise and dire disaster; hence the studious development for these units of lubricating devices and systems that are practically automatic in operation and require infrequent attention. Engines will go from 200 to 500 miles on a charge of oil. Gearboxes and axles will go 3000 to 5000 miles on a charge of lubricant.

When we turn to the consideration of the chassis bearings mentioned above we find most of them equipped with lubricating devices of the crudest sort, in spite of the fact that in many cases, on spring-bolts and universal-joints, the pressures per square inch are as high as those encountered on the crankshaft bearings of the engine. In addition, the ends of the bearings are, for the most part, exposed to the dust and mud of the road, while atmospheric moisture can enter almost at will. As a result these bearings deteriorate rapidly, entailing gradual loss of power, hard riding, difficulty of control, spring breakages, squeaks, rattles and a general looseness that adversely affects other parts of the chassis. The fact that the chassis bearings can function at all under these conditions, and neither produce a startling outcry nor actually breakdown for some time, has been responsible for much of the lubricating neglect on the part of both the manufacturer and the user.

The user pays a big bill for this neglect, however, and the truck builder feels the reflection of it in sales resistance. In this Country the estimated direct cost of truck repairs due primarily and secondarily to poor chassis lubrication is between $15,000,000 and $20,000,000 per year, a truly staggering bill. On the other hand, at only 50c. per hr. the labor charge to lubricate properly our trucks with the devices now furnished, would cost over $40,000,000 per year. It can be seen readily, therefore, that the truck user has actually been justified to some extent in his neglect of these parts, for, even if he gave them the attention that the builder desires, he would still have some repair bills, say $5,000,000 per year, and the total direct economic loss would exceed $25,000,000 annually.

The indirect loss to the user, the loss of earnings while the trucks are being repaired, runs from $30,000,000 to $35,000,000 annually. This is not always taken into consideration by owners; otherwise they would pay more systematic attention to chassis lubrication, and make a more insistent demand upon truck manufacturers for means to allay this heavy expense.

Except at one or two points, grease as a chassis lubricant has been acknowledged by close students to be inferior to oil and it is becoming less popular. Grease is a dirt collector and carrier; it is not uniform and is only part lubricant; it will not spread over a bearing by capillarity; it can be forced over the slack side of an oscillating bearing without reaching the load side, and as it exudes from the ends of the bearing it gives the misleading impression that the bearing is lubricated; it entails a high labor charge for application. Oil is a much better lubricant, for it carries no inert matter; even if dirty it can be filtered as it is fed; it spreads completely over a bearing by capillarity; it can be fed automatically; it can be led from one point to another in series; it is cheaper. The average oil-cup, grease-cup or fitting, however, is an excrescence, easily damaged or broken off. It admits dirt and moisture to the bearing, and its repeated filling calls for a heavy labor item.

An early attempt to embody thorough and automatic chassis lubrication was made in 1916 by a Pacific coast truck builder who embodied small oil-reservoirs, or magazines, in the brackets that held the chassis bearings. In this system the oil is filtered and fed by wicks to the bearings whenever the motion of the bearing calls for it. About once a month the reservoirs are filled from a spout can. This magazine system was so satisfactory that the 20,000 Class B Trucks for the United States Army were so equipped. After 3½ years of hard service in the New York district 300 of these trucks were overhauled, and the inspection showed that less than ½ per cent of all the chassis bearings fed by the magazines showed appreciable wear. This is a vast improvement over the usual condition of such bearings, which in many cases must be renewed entirely, both pins and bushings, after 2 years' service. The surplus oil from the spring-bolts spread down the springs, kept them soft and flexible, and practically eliminated spring breakage. A magazine type of lubricator for spring-shackkles that is equipped with a rapid fill opening is illustrated in Fig. 12.

By piping the various magazines to a few convenient points at the side of the chassis, they can be filled in less than 10 min. The first applications of this system had no provision for regulating the feed, which was much more than sufficient. Later improvements regulate this so that the magazines need not be filled oftener than once in 2 months. The national labor charge for truck chassis lubrication can be reduced in this manner to $500,000 per year. The chassis-bearing repair-bill can be cut to an insignificant figure, as can also the lay-up loss due to these repairs. A conservative estimate of the direct and indirect savings on our 1,010,700 commercial cars is $50,000,000 per year. This alone would buy 15,000 new chassis. It would buy 20,000 chassis if these were built in one plant each year.

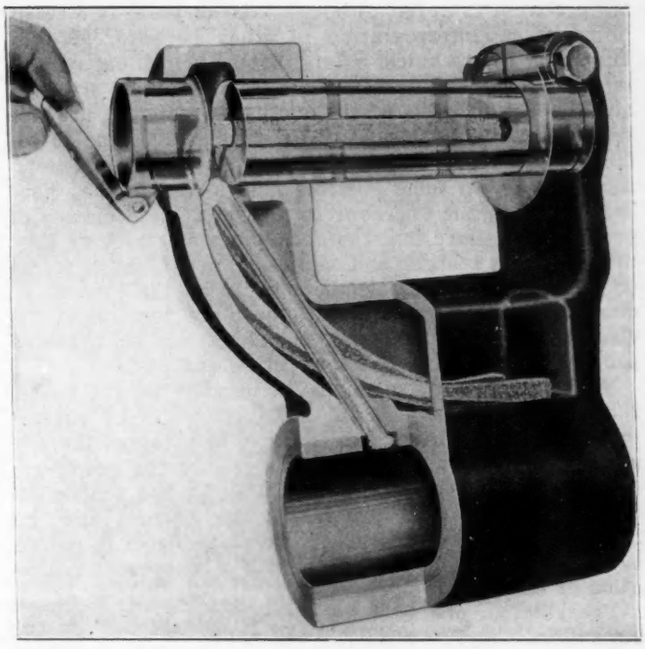

FIG. 12—A MAGAZINE LUBRICATOR FOR SPRING-SHACKLES WITH A RAPID FILL OPENING

The next few years will likely see much active competition in motor-truck service. Refinement of detail and simplification of operating features will be emphasized.

Many buyers today are not sure as to what features are essential and which ones are non-essential. Few buyers have any fundamental knowledge of motor-truck design, or the compromises necessary to produce a successful design. In purchasing they stress this or that point without absolutely knowing its value or the effect of it on the cost and operation of the truck as a whole. This makes for differences of opinion among builders as to what the trade wants. Neither buyer nor seller gets any permanent benefit under these conditions.

Frequently the buyers' experience does not qualify them to pass judgment on the propositions that are offered. Once the full picture is before them, there are few executives who are not qualified to judge the situation and make a proper decision. Such decisions would soon clarify the situation for both buyer and seller.

In the long run motor-truck design should tend toward such standardization as has been adopted to so great an economic advantage by the Master Car Builders' Association, which permits railroad rolling-stock to be repaired quickly and cheaply in any part of the Country. This need not restrict initiative or halt improvement, but will make any innovations conform to good practice, as determined by careful analysis of cause and effect, and long study in the application of the results.

THE DISCUSSION

PRESIDENT B. B. BACHMAN: — Regarding the brief analysis that Mr. Myers made as to the relative stiffness and strength and the uses of higher grade material, I

am prepared to agree, although I think there is a possibility of misinterpretation of what he said. We all know that the technical points that he brings out regarding the form of a structure and its effect upon stiffness, and the lack of effect of the quality of material, are well taken; however, I feel that Mr. Myers has gone to extreme lengths to a large extent in this paper in endeavoring to clear up some possible misstatements that have been made in the endeavor to market certain classes of product. I believe that the advantages of elasticity have not been fully realized and, while I do not think the frame or the front axle are members in which the element of elasticity is a desirable factor, there are portions of the chassis structure in which elasticity can be obtained properly by the form of construction and design.

The Hotchkiss drive, in itself, permits weight reduction in the chassis design. The reduction of chassis weights and the advantages that can be obtained thereby are a result of study and an analysis of the power requirements and the engine size used in the vehicle, in conjunction with the gear-ratios, the gearbox and the rear-axle. Such considerations have a tendency to reduce the tare weight of the chassis, with a consequent realization of economy in operation.

Probably no one is more sympathetic to standardization than I am. I have had the honor of being Chairman of the Standards Committee for 4 years, and I have been associated with the standards work in one capacity or another for many years, practically since the inception of that work in the Society. But I do not concur fully with what Mr. Myers says with regard to the desirability of the standardization he outlined. If I interpret correctly the closing paragraphs of his paper, he is making a plea for interchangeability of essential components of motor vehicles, that would undoubtedly be detrimental to initiative and the development of design.

He uses as an analogy the work accomplished in railroad circles by the Master Car Builders Association. In railroad practice a freight car may leave New York City with a load and, without having its load changed, cross the Continent, traversing an air-line distance of 3000 miles, and possibly going many hundreds or even thousands of miles more than that, dependent upon the methods of routing. In that time it would pass over a number of different railroad systems. It is evident that there should be a considerable degree of interchangeability. The most obvious standard is that of the gage of the tracks. In the matter of repairs in the various roundhouses the stocks carried must be interchangeable. In spite of what we have seen in the past few years, under abnormal conditions, of long truck-transport, it does not seem to me that we will ever approach a condition entirely analogous to that of the railroads. While the benefits of interchangeability that Mr. Myers points out have a certain foundation and can be defended along logical lines, I believe there is a reverse side of the picture.

There is room for reasonable differences of opinion on the matter, without any actual antagonism from either side. It is possible that, as the motor-truck industry gets out of its swaddling clothes, some of the things Mr. Myers has outlined will come to pass. Certainly, history tells us that the views of men of vision are needed to point out things that some of us who are more closely tied to details think cannot be accomplished.

In regard to the subject of wheels, Mr. Myers has reported the results of some tests with the idea, as I understand it, of refuting certain sales statements that have been made. The data he has brought forward would not sway me one way or the other. I feel that the results which he points to, and which he has definitely qualified, as secured from a small number of trucks, really do not tell us anything. At the same time the claims he is attempting to refute have not, so far as I know, been established otherwise than from a controversial standpoint.

On the other side of the case, Mr. Myers refers to the fact that during the last few years an unsatisfactory quality of wood wheel was manufactured and sold with disastrous results. That factor alone is, I believe, responsible for the rise of the metal wheel to the quantity production it has attained. The only fear I have had with regard to the wood wheel is from the standpoint of the felloe stock. I have had no fear of the spoke stock. The felloe stock, particularly in the case of large-sized wheels, should be improved. Designs have been proposed, and some of them have had a considerable amount of practical trial. That appears to eliminate the difficulty of wooden felloes and offers the possibility of satisfactory service from substituting steel while retaining the essential characteristics of the wood wheel. I believe that the serviceability and satisfactoriness of the wood wheel and of the metal wheel are dependent more upon honest workmanship and good quality of material than upon anything else. Either construction will give good service under proper conditions.

The questions and theories that have been raised with regard to flexibility, radiation of heat and the like are all matters of conjecture and possibly matters for future research. So far as I know, none of us has had time to investigate and obtain data to substantiate any one of these various thoughts or theories.

C. T. MYERS:—Our chief problem in truck design is to secure a construction that will offset impact blows. The more flexible and more resilient the construction is, the better it will resist impact blows. I agree with Mr. Bachman that the frame weights and all other weights should be cut down to the limit. The point I tried to make is that there are many people who do not know what they are talking about at all and never had to spend months and years in getting a truck on the road and keeping it there, but make claims of the possibility of vast weight-reductions that, so far as we can see at present, are not tenable. Some of them claim to reduce the weight of a motor truck by one-third. That is absurd. Accomplishing a 10 to 15-per cent weight-reduction in the average truck is doing exceedingly well and it takes extremely good designing to do that without an excessive increase in cost.

As to standardization, I have gone the full distance of what I think are the possibilities. There is considerable conjecture as to the probabilities. I believe that there is a fair analogy between the Master Car Builders' standards and those of the motor truck; not that many motor trucks will cross the Continent in a week or two and demand service in San Francisco, but that trucks of a dozen different makes will be built and sent to San Francisco, to Canada, to the South, to Australia, South Africa, India and elsewhere. Why should each truck builder be called upon to maintain his trucks at every point where he sells a truck? Each manufacturer must do this if he is to keep his trucks in service there and hold his business. Why should each one be called upon to maintain wheels that fit no truck but his own, to maintain bearings in those wheels that vary only slightly from those made by the other manufacturers, different steering-pivots, bushings and a hundred and one little details that do not make a particle of difference if they can be picked out from a series of standard sizes when he designs and builds his truck? I am a designer myself

and I dislike to be hampered, but I have been up against the practical side of designing in the past several years, particularly from the motor-truck user's side. The user is certainly in a serious predicament when out of touch with satisfactory service parts; it is maddening to find that one cannot replace some particular part because it differs by a few thousandths of an inch from a similar part that is available.

As to claims concerning wheels, I particularly state that what I have set forth does not prove the case finally. I have used data from carefully made tests, those of a man that intended to equip all his trucks with steel wheels. I realize that all sorts of questions and doubts can arise in the minds of the people who are interested in this matter, because I have done much research work for people who make wood wheels; and it was stated to them several years ago that the steel-wheel claims would not hold water. At about that time I was acting in a consulting-engineering capacity for three different truck builders and this question of wood or steel wheels came up repeatedly. The statements of most steel-wheel salesmen simply cannot stand up against careful analyses. There are some things about wheel design and use that are not fully appreciated in the industry. The same condition exists with regard to a great many other details in a motor truck. But we should know these things. The buyer must know them; otherwise he cannot express his desires. He is the one who pays the bills, not the motor-truck builder.

RUSSELL HOOPES:—Other than the tests described by Mr. Myers, I do not know of authentic data of this kind. As Mr. Myers says, we have heard many statements but have not seen them supported by facts.

We hope that the good work started with the standardization of axles and hubs will be carried on and that the wheel standardization will follow, so that a truck user can stop at any service station and get a new wheel that will fit his axle and hub equipment, and tires that have been standard for many years.

Considering some of the recent remarkable results secured with aluminum alloys, I believe that we will use aluminum for parts of trucks that heretofore have been under too severe a strain and too expensive. Aluminum will save decidedly in weight, but it may be too expensive to use extensively. In regard to the question of unsprung weight, I hope that in some way additional information will be available.

The paper gives the result of tire tests comparing the cast-steel wheel and the wooden-spoke and wooden-felloe wheel. The company in which I am interested makes a wooden-spoke and wooden-felloe wheel of the best possible construction and has found that the wood felloe is a source of weakness. To overcome this it has used a comparatively simple method of inserting a flat-plate washer between the spoke-end and the counterbore in the wood felloe, and has never had the least trouble with this. The same results have been obtained by the Pierce-Arrow company, in its form of spoke sockets or shoes, and also by the White Motor Co. in making its wooden-spoke and wooden-felloe wheels. The latter company accomplished the same results by using about twice as much timber in the spoke at the felloe shoulder as was necessary to make the head. This gave the spoke ample bearing so that it did not become felloe-bound after hard service. Our company has felt that the metal-felloe truck-wheel has altogether eliminated the wood-felloe.

The matter of chassis lubrication is an essential feature that is commonly neglected. As Mr. Myers shows, an enormous saving can be made by proper practice. Oil is much superior to grease.

Concerning the weights of wheels in connection with unsprung weight, the wood-felloe 36 x 12-in. wheel such as we used to make weighed 216 lb. The weight of the 36 x 12-in. metal-felloe wheel we make is 166 lb. The weight of a 36 x 8-in. metal-felloe wheel, with 2½-in. spokes, is 101 lb.; whereas our type of wood-felloe 36 x 8-in. wheel would weigh 140 lb. In our 36 x 12-in. wheel the metal-felloe makes a saving over the wood-felloe wheel of 50 lb. The metal-felloe 36 x 8-in. wheel saves 39 lb. over the same size of wood-felloe wheel.

These facts demonstrate that the S.A.E. Standard wood-felloe depths have been unnecessarily great since the advent of the metal-base tire that has superseded the fabric base. The tire base strengthens any wheel on which it is placed so much more than the old fabric base that the S.A.E. Standard dual-felloe depths probably could be reduced 25 per cent and the single-felloe depths 50 per cent; in fact, where the single S.A.E. Standard bands are ⅜-in. thick, they probably are strong enough to stand the work without any wood felloe, when a pressed-on tire is mounted.

The wheel weights I have stated are correct, but different wheels will vary in weight on account of the difference in the specific gravity of the various kinds of timber used in the wheel; also, there is a variation in weight of the different pieces of the same rolling of steel used in the felloe band, in the drop-forged sockets and in the plate washers.

MR. MYERS:—In regard to the point that the S.A.E. Standard wood-felloe thickness could be reduced by 25 per cent in some cases and 50 per cent in others, it seems to me that it is advisable to use the thickness specified in the S.A.E. Standards at present, or else use no wood at all. In assembling a wheel, if we have too thin a wood felloe it will not withstand the pressure of the press in which the wheel is put together. It seems to me that it is somewhat risky to advocate cutting 50 per cent off of the thickness of the felloes, and that we should use the present standard until we shall have experimented further with light felloes.

J. H. WAGENHORST:—My experience has been in connection with the substitute for the wood-felloe wheel that Mr. Bachman mentioned. I started on this work in 1913. It consisted of placing steel-felloe wheels instead of wood-felloe wheels on passenger cars, principally on the large-sized No. 66 Pierce-Arrow cars. The result of that development today is that practically all of the wheels that are used on passenger cars now have steel felloes. Our production alone has been about 2,000,000 sets in the last three years, and that may represent one-half or probably somewhat more than one-half of the steel-felloe wheels being used by automobile builders. The Packard, Cadillac, Hudson, Buick, Nash, Overland and Ford companies are using steel-felloe wheels exclusively. Our own factory is making steel-felloe wheels entirely. The wheel itself is considerably lighter than the wood-felloe type, speaking of demountables, ranging from 6 to 16 lb., depending on the size. The average increase in strength is approximately 25 per cent. There is very little change in wood lengthwise with the grain; there is a considerable change across the section. We have taken spokes and kiln-dried them to 4 per cent of moisture, measured them very accurately, immersed them in water for 2 weeks and found, on the second measurement, that there is practically no change in length overall; whereas the cross-sectional change runs as much as ⅛, or possibly ⅞ to 1 in. The crushing strength across the grain is about one-sixth to one-eighth as compared to lengthwise strength.

One of the important questions that was brought up

originally in regard to steel-felloe wheels was that of shear-off of the spoke. All of these spokes are supplied with a fillet, that is the natural result in form, and a socket in a steel-felloe base, so we have it somewhat smaller in section, although at the point of shear in the steel it has a considerably greater section, giving a greater endwise area as well as shearing strength.

A MEMBER:—In looking over Fig. 11 of Mr. Myers' paper, I note that truck No. 175 averaged about 0.008 in.; truck No. 172 about 0.017 in.; truck No. 168 about 0.019 in.; and truck No. 162 about 0.026 in. of wear per 1,000,000 commercial ton-miles. Mr. Myers pointed out that truck No. 175 was driven by an extremely careful man. I wonder if there is any significance in connection with that. It seems to me that possibly an analogy can be drawn there between a very careful man's driving and the well-known behavior of a certain car on tires. I know that it is impossible to slip or spin the wheels in starting a certain car from a standing start under any condition that I have encountered. Does he not think that the tire wear is more the result of braking and accelerating than of the load imposed on the tires themselves?

MR. MYER:—It is not at all fair to compare the wear of the tires between trucks; the conditions were not the same. I give several different variables in my paper. The tests were made as carefully as possible to get some comparative data on wheel service. If the steel wheels were better on account of being more nearly round, it ought to show up as an average on 20 front tires, particularly when we were so careful about the tires. I cannot say that those tires were all exactly the same; I do not believe they were, but I do believe they were very nearly the same. As I pointed out, a comparison of the diagrams shows that all of the tires wore in separate and distinct groups, evidently controlled by the trucks on which they were operated. Truck No. 175 gave the best results; truck No. 172 was next, and truck No. 162 was last. There were marked differences between the worm-drive and the chain-drive trucks on which the rate of wear was greatest, and it is not at all fair to compare the tire wear. What I have given in the paper was just an indication that minimum unsprung weight is by no means all of the story.

Mr. Bachman will acknowledge that as soon as he tries to change the design of anything in his two-cylinder truck very much, he has to change the whole truck. I have seen a change in the size of a bolt in a truck modify 28 other different parts, some of them 6 to 8 ft. distant from the bolt that was changed. The inter-relation of parts in a motor truck is very intimate, the compromises are manifold and good judgment and long experience are needed before one is able to make a compromise. Many conclusions are being drawn from insufficient evidence.

W. B. BUTTERICK:—Has Mr. Myers seen the steel wheel used on the London General Omnibus Co.'s vehicles? It is not by any means so bulky a steel wheel as that which he illustrated. The London General Omnibus Co. operates about 4500 buses on the streets of London and all have steel wheels. I think one will not find a wood wheel manufactured in Great Britain; there are practically none on any truck in London. I find that the London General Omnibus Co. has reduced its tire costs 2d. (4 cents) per mile over those obtaining with wooden wheels, since they began using steel wheels. In the case of the omnibus, the wheel is built especially light in weight for that purpose only. The vehicle has an ash frame between two steel clinchers or flitches. Possibly that is the reason why they get a better tire mileage, with the resiliency in the frame, not at the wheels.

MR. MYERS:—The wheels used by the London General Omnibus Co. are very light steel wheels, but the difference in the tire cost cannot be attributed entirely to steel wheels. When it changed from wood to steel wheels it also changed a number of other things. The Fifth Avenue Coach Co., in New York City, uses a design very similar to that used by the London General Omnibus Co. It uses a steel wheel that is very well designed and very light.

There is this difference to be considered in regard to the steel wheels used by these two companies and the steel wheels used by the average motor-truck builder. The Fifth Avenue Coach Co. runs its vehicles on a smooth street and straight ahead all the time; but the London General Omnibus Co.'s vehicles run on rougher roads. Some of the streets have cobblestone pavements and the vehicles have more side-thrust to withstand, but not anywhere near the amount of side-thrust that a truck in regular service has. The tire-mileage cost of the Fifth Avenue Coach Co. was reduced greatly between the time it used wood wheels some 6 years ago and the present; but tires have been improved within that time to an extent where they will give from 70 to 80 per cent greater mileage regardless of the type of wheel, and they have also been reduced in price, so that one cannot get any direct comparison on the wheels themselves. The prime reason so many steel wheels are used in truck construction abroad is that they have great difficulty in getting good wood. It was very difficult to get good hardwood in this Country a few years ago; the Government has requisitioned practically all of the hardwood. However, the Saurer Co., a leading foreign motor-truck builder, still uses wood wheels; some of the wheels illustrated in my paper were made by that builder. That company also uses fewer spokes in its wood wheels than we use in this Country, to obtain the maximum resiliency. This company makes its own wheels. When a wood wheel is made properly, it is superior to the steel wheel, because of its greater resiliency. The French and the Swiss had a sad experience with the steel tire a few years ago, when they used motor trucks over cobblestones. The steel tire produced so severe an impact all the time that buildings deteriorated from great cracks in the foundations, all along the line of travel, and they had to stop using the steel tire. The Saurer Co. appreciated the fact that great resiliency is essential in tires and was the only builder that did not use a steel tire.

MR. BUTTERICK:—Why do not the White and the Pierce-Arrow companies use the wood wheel? I believe they said they could not get any suitable wood.

MR. MYERS:—That is exactly the Pierce-Arrow company's reason. This company made its own wheels and they were fine ones. Records showed wheels that had been in service from 1 to 5 years in the Arizona and New Mexico districts where some wheels dry out in a few months and go to pieces, but the Pierce-Arrow company's wood wheels had practically a perfect record of service. But those wheels were properly dried, finely finished, excellently fabricated and thoroughly painted. Two coats of primer were put on them as soon as they were fabricated and before the wheel went out for test. Before that truck got away from the plant it had five coats of paint. It was a good truck and the man who bought it took pride in it and painted it from time to time. All material must be used with respect to its characteristics, and moisture must be kept out of a wood wheel. It can be done without any trouble if one recognizes that need and cares for it. I seem to be a champion of the wood wheel, but I do not want to take that attitude. I am trying to face facts. Let the man who has the facts

of the matter in his possession present them and let us use them as we can.

J. E. WOLFF:—Very little good hickory is grown abroad. I believe this is the chief reason that more wood wheels have not been used in London. Aside from that, we have supplied several hundred sets of wood wheels to foreign companies. These have been very satisfactory, as there has not been one complaint; so, there are wood wheels abroad as well as steel wheels.

ERWIN L. SCHWATT:—Mr. Myers' paper states that "the average rate of wear of the rear tires on the chain-drive trucks was 53 per cent in excess of those on the worm-drive trucks." It seems that, when the chain is under tension, the wheels will slip a little when the loaded frame changes its position relative to the axle due to the roughness of the road.

MR. MYERS:—The figures are not truly comparative between trucks, or for unsprung weights; but if a man says that the truck with the light axle will show decreased tire wear, how does he reconcile that statement with this condition where it does show increased tire wear? They did not measure any clutch performance or check up on the drivers. They sent each driver out on a truck equipped with a wood wheel on one end of each axle and a steel wheel on the other. The driver did not know what was going on at all, and operated the truck just as he thought he ought to operate it.

MR. SCHWATT:—That skidding action probably is the reason for the excessive wear, and the relative weights of the rear ends do not enter into it. In the case of the worm drive we have the possibility for a skid, and also in the chain drive there is an actual skid.

MR. MYERS:—That *might* be true, but that is just one of a number of variables that can enter into this matter. How can anybody make flat statements that this wheel or that wheel can accomplish all these economies when so many other variables can more than offset any possible saving?

MR. BUTTERICK:—The Albion truck people were using the method of automatic lubrication with a wick in 1908.

MR. MYERS:—Possibly. However, they did not make substantial magazine brackets, but used oil-cups which are excrescences. When one got knocked off, it was forgotten that its pin needed any oil.

OUR HIGHWAYS

THE United States is founded upon the possibility of maintaining a sufficient and efficient transportation system.

In 1921 our estimate of the accumulated investment in highways for the 11-year period was $2,526,000,000, exclusive of the amount we have spent for maintenance each year. The estimate of rolling stock values is $8,790,000,000. That is, there has been over three times as much investment in rolling stock between 1910 and 1921 as we have expended during the same period for highway construction.

I estimate that it costs the American individual, each man, woman and child in the United States, about 1 cent per day for the highways. Our estimate of the amount that the Federal Government contributed last year toward the total bill for highways was only about 14 per cent, and the portion of the cost that the automobile paid in direct taxes we figure at about 19 per cent. That is, the Federal Government and the automobile paid about 33 per cent of our total bill. That leaves 67 per cent to be paid from other sources, largely taxes, partially those due to the floating of issues of bonds and partially direct levies.

If our estimate as to the investment in motor vehicles is somewhere near right at $8,790,000,000, a 20-per cent depreciation of the motor vehicle is over $1,600,000,000 per year. I do not know how much of that depreciation we can prevent by improving the roads, but if we can cut the bill for repairs by $600,000,000 that would be enough to pay our total road bill for last year.

It will not be increasingly difficult to carry the traffic over the highways. It will be increasingly easy if we study out the scientific principles that we must know and apply in order to carry heavy loads upon soils such as we have and which vary from place to place in the United States. If we were building all roads over good gravel or over good sand subgrades, we would not need to worry about how heavy the motor vehicles become, because all we would need is a thin slab on top to take care of the wear under the wheels; the subgrade would do the rest.

I want to contradict the oft-heard remark that our highways are going to pieces now. During the war practically all maintenance was withdrawn from the highways during the period when we increased our rolling stock over them more than 1200 per cent. It has taken the whole time since the war period to bring those highways back. Generally the highways are in better condition to-day than they have ever been before, notwithstanding our rolling stock over them has increased more than 1800 per cent.

The Federal-Aid Highway system will not for many years extend beyond the system of main highways.—T. H. MacDonald.

FOREIGN TRADE

THE inability of the cotton planters and the farmers of America to sell their produce abroad last year induced the American Government to reconstitute the War Finance Corporation and to create export credit to facilitate exports sales, and the ability of Continental Europe to buy cotton and other produce in recent months in part arises from the assistance afforded to them by this corporation. But the assistance granted is only of a temporary character, and this method of meeting the difficulty offers no permanent solution of the problem. Until steps are taken to induce the American people to buy foreign goods more freely, so that American exports and interest can be paid for by imports of goods, the problem will, of necessity, remain unsolved.—Sir George Paish.

Practical Road Construction

By R. C. SCHOEN[1]

MINNEAPOLIS TRACTOR MEETING PAPER

THE viewpoint from which the paper is presented is that of the engineer-contractor. Since mobility of a road-construction outfit is of prime importance, the camp equipment described was designed to meet this requirement in an unique manner, dependence for power being placed upon the track-laying type of tractor.

Because of having used both tractor and horse-drawn outfits on the same work, the author has had an exceptional opportunity to make comparisons between them. This he does in considerable detail, daily cost data being presented in tabular form, and finds that the evidence favors the tractor for use in practical road construction. The subjects discussed include finishing road work, tractor operation, daily output of work, repairs, wheeled tractors, lubricants, earth removal and grading machinery.

THIS paper on practical road construction is presented from the viewpoint of an engineer who entered the field as a contractor in that line. It includes some of the impressions acquired during 3 years of experience in the operation of outfits on such work. I entered this field after nearly 20 years of experience as a construction engineer, having had active charge of railroad and highway work during a large part of that time. Naturally, I felt that I was familiar with all the intricacies of operation; but, I am willing to admit that within a short time I found there were numerous things I did not know, and I have been brought to a realization of that fact many times since.

CAMP EQUIPMENT

Camp equipment must be the first consideration in the organization of a practical and efficient road-building outfit in which tractors are to be the chief power. Highway-construction conditions are very different from those surrounding railroad construction. There are transportation advantages in railroad work, especially on reconstruction, that do not appear in road work. A road job may be, and probably is, located several miles from a railroad. This means an overland move. In all likelihood the next road job will be located several miles distant, perhaps on another line of railroad; so, one cannot afford to ship an outfit a long distance, especially when the tariff is high. Therefore, the mobility of the outfit must be one of the chief considerations. The units must be handled easily and arranged for coupling into a train. Tents for horses and men were much used formerly, but these are high priced and are quickly destroyed, especially in the prairie country where the wind blows almost continually. I have not used tents in the last 2 years. The men are housed and fed in cars. These are generally about 12 x 24 ft. in size, built fairly light and well braced. The cars are mounted substantially on separate trucks and, when placed in a train for moving, are hooked to a heavy cable which runs underneath the entire string. No strain due to pulling one car by another is placed on the individual vehicles.

Up to the present, I have not motorized the earth-hauling equipment. Tractors are used only on the graders; horses on the wagons. Horses, of course, need barns. The designing of barns that could be easily moved presented one of our greatest difficulties. During the first two seasons we used sectional barns mounted on skids. On short moves, a tractor would drag these barns, one at a time, to the new location, straining them badly in the process. On long moves they were knocked down, having been built in sections which could be handled by four men. They were then reassembled and set up at the new location. This method was unsatisfactory and the buildings were practically useless after one season.

We then designed a barn that could be mounted on wheels and have since made one that I consider thoroughly satisfactory. I now have barns mounted on wheels that can be prepared for movement in 10 min.; they can be reset almost as quickly. These barns are 26 x 32 ft. in size and can accommodate 12 horses comfortably. A half section of the roof on either side is made to drop down. This makes the width while moving less than 12 ft. and avoids obstructing the highway; it also permits loading and shipping on flat cars if so desired. They can be coupled together and placed in a tractor train, one being hitched to another, without danger of being pulled apart. Thus every building on the camp can be placed in a train behind the tractor and moved at one time, leaving the lighter equipment and odds and ends to be brought up by the horses. Last season with such an outfit I made one move of 32 miles in 1 day. Later, I made two moves of 24 miles each in 1 day and experienced no trouble. The same outfit could not have been moved in the same time by horses. The power in this instance was furnished by a tractor of the track-laying type.

TRACTOR VERSUS HORSE-DRAWN EQUIPMENT

During the last season, I was well situated for making a comparison in the operation of outfits handled by tractor and by horses, having one outfit that was handled each way. These outfits were operating in the same district all summer and, for a time, they were on the same job, so that the soil conditions were identical.

Aside this one job, the tractor had the most difficult work; in one place the soil was very sandy and stony and in another it was heavy clay containing a large percentage of boulders. The month of June was extremely hot and dry and we were operating in the sand during that period. The wagons suffered severely here, because they sank deeply into the sand and were a heavy drag even when empty. The heat and dust made breathing difficult and there were times when the machines were enveloped in such a heavy cloud of dust that they could not be seen a short distance away. Nevertheless, the machines kept going and would have worked at maximum efficiency throughout if the wagons could have stood up under the strain; but we were compelled to slow up. I have often thought that a smooth running, completely motorized outfit would have finished this job in one-third the time.

On the two jobs mentioned, we encountered many boulders deeply embedded in the soil. Some of these boulders weighed several tons and, without adequate power on the job, it would have been necessary to break them with explosives in order to handle them. They were nearly all removed by the tractor by the simple process of digging around them, putting on a heavy chain and snak-

[1] Highway contractor, Ortonville, Minn.

ing them out of the way. Boulders which could not possibly have been handled by horses were thus removed with a minimum loss of time.

On one of the jobs the road passed through a small lake which was about 1200 ft. wide. The water reached a depth of 10 ft. or more for a large part of that distance. A special bulldozer was designed and built to push the material ahead. This contrivance had a blade or pusher 8 ft. wide, was heavily built and performed its work well, with four heavy horses for power; but, in my opinion, a small tractor would have been better in such a case than horses and I would like to see a practical machine built for use with a small track-laying tractor.

The soil on the job where the horse-drawn outfit and the tractor both worked at the same time was a heavy gumbo. The cuts were light and much of the material was taken from the sides and hauled long distances. Here I had a chance to make a comparison of performance, and that comparison was very favorable to the tractor. On this class of work, which consisted of a series of short cuts and long light embankments, turning the machine was an important item. On several occasions, I found that the average time consumed, from the time the plow was raised until it was set in the furrow ready to go, was 45 sec. for the tractor and 1.5 min. for the horse-drawn machine. This means something throughout a season's run. There is also a marked saving of time in starting to work. For instance, one day I held the watch on the tractor when the machine was working about 800 ft. from camp. From the time the foreman called "hitch up" until the first wagon was loaded just 10 min. elapsed; with the horse-drawn machine, under similar conditions but with about 100 ft. farther to go, 18 min. elapsed. This was a clear saving of 8 min. These items may sound small, but they are important when considered as a part of the daily saving over a period of 7 months.

Another item that should not be overlooked when comparing tractor and horse-drawn outfits is road finishing. With the tractor outfit, we made a practice of blading up the completed work after hours or occasionally on Sunday though, generally speaking, I do not approve of Sunday work. For this purpose I used a heavy grader having a 10-ft. blade. I have found from experience that a machine having a 10 to 12-ft. blade is the only one that will finish a roadbed in heavy soil properly, and that such a machine must be drawn by a tractor. As stated, this work can be done after hours where a tractor is employed as a part of the regular equipment. It was our custom to rough in from 0.5 to 1 mile and then go out for 2 or 3 hr. after supper and blade it down. By keeping up with the finishing in this way, the amount of sand-papering required at the completion of the job is minimized and the highway engineer and the traveling public are kept in good humor. With an all-horse outfit, the preliminary blading is done with a machine having a 7-ft. blade and drawn by six horses, but a light machine of this kind cannot do the work as well as the heavy machine. On the completion of a job by the horse-drawn outfit, it was always necessary to swing one of the tractors and a large blade grader over and do the final blading. This sometimes meant moving a tractor several miles, loss of time when it should have been working and loss of time in moving it back. Under present road specifications and system of inspection, a tractor for finishing is almost indispensable.

TABLE 1—DAILY OPERATING COST OF TRACTOR AND HORSE-DRAWN OUTFITS

Tractor Outfit		
Operator, at $175 per month and board		$8.75
Gasoline, 28 gal. at 23 cents per gal.		6.45
Crankcase and Transmission Oil, 2 gal. at $1 per gal.		2.00
Track Oil, 3 gal. at 20 cents per gal.		0.60
Track-Roller Grease		0.20
Interest on Investment		3.00
Repairs for Season, including overhaul		4.00
		$25.00
Depreciation, subject to question		15.00
	Total	$40.00
Horse-Drawn Outfit		
Rental, 8 teams at $35 per month		$10.80
Hay and Feed		16.60
Machine Driver		6.00
Gig Driver		4.00
Push Driver		4.00
Extra Pay for Wheel-Stock Man		1.00
Harness Repairs		2.50
Horseshoeing		1.10
Veterinary Charges and Medicine		0.50
	Total	$46.50

Operating Costs

The cost of operation, given in Table 1, is of interest. It affords an opportunity for a comparison between tractor and horse-drawn outfits and also for the comparison of actual costs with the data furnished by the builder. It shows a difference in favor of the tractor outfit of $6.50. It states only the cost of power, as the remainder is practically the same, and the costs of operation differ very little.

In making comparisons between tractor and horse-drawn outfits, the winter expense should be considered also. If a contractor owns his stock and is fortunate enough to get into a lumber camp for the winter, all well and good; but, if such work is not offered, as has been the case this past winter, and he is compelled to winter the stock himself, he piles up a bill of expense that would not be incurred with a motorized outfit. Another item is the smaller expense of a motorized outfit when tied up by rainy weather. Last fall we had bad weather that lasted 2 weeks and could work only 2 days out of 14. The expense of the tractor outfit during that time was only slightly more than one-half that of the horse-drawn outfit.

There is a wide difference among operators in the manner of handling a tractor, but there is only one right way. I had two operators early in the season. One came well recommended and apparently knew his business; he remained about 6 weeks. Afterward, I got a young man who was a real operator who reduced the daily gasoline consumption from 42 to 28 gal. This of course reduced the consumption of oil and also was much easier on the engine.

Daily Output and Repairs

There was, in my experience, very little difference between the daily output of the tractor and that of the horse-drawn outfit under similar conditions. Heretofore I have used the contractor size of elevator with a 36-in. carrier. Next season I am planning to use the heavier machine with the 40-in. carrier, as there is ample power to handle such machines. The best working gear for the 10-ton tractor is the low gear, but I have found this to be rather too slow a speed for ordinary work. In my opinion, 2 m.p.h. on low gear would be about right. This is about the speed at which a machine is drawn by 16 heavy horses.

When starting to use the track-laying tractor with the elevator grading machine, I feared the grader would not withstand the strain of continually being stopped and started. I have found this fear to be groundless. The tractor starts the grading machine more easily than horses do, there being no lunge forward but an easy pull that throws no great strain on any particular part. Fewer repairs were required on the machine operating behind the tractor than when it was drawn by horses.

I can say very little on the subject of repairs for the track-laying machine, as I have had this tractor but one season and the repairs have been comparatively light, consisting of small items such as valve-springs, gaskets, magneto parts and the like. Only one section of track broke during the season and no pins were replaced. No delays whatever were caused by breakdowns but this, of course, should be true of any high-grade machine for the first season.

Although I have been discussing tractors of the track-laying type entirely, this does not mean that I am altogether ignoring the wheeled tractor. I have one large wheeled tractor that has been in operation for seven seasons. Last season it traveled a distance of nearly 3000 miles on work, which consisted of turnpiking township roads, heavy maintenance of State roads and finishing new work. The grader used had a 12-ft. blade. This is good work for an old machine, but a comparison of costs between this tractor and the track-laying tractor cannot be made consistently because the old machine naturally used much more gasoline and oil than the new one. The wheeled tractor worked in long stretches, which called for very little turning. I gave up trying to use this tractor on wagon work in short cuts where frequent turning is necessary, because too much time was lost; but, on long, straight-away work, I have found it very satisfactory.

I have been particular to use the best oil lubricants, obtainable, regardless of price, and have adhered strictly to the instructions of the builder in this respect, although salesmen wished to sell me oils at a much lower price that were said to be just as good as those I was using. Other oils may be as good as those the builder recommends but it seemed unwarranted to change to some other oil for the sake of saving a few dollars. As a result of persistently using the oils indicated, I have had no bearing trouble. All parts of the machine are in excellent condition and the expense of overhauling after a full season's work will be very light. I have had the cylinders of the engine of the new tractor rebored and new pistons fitted. This would not have been necessary under ordinary conditions, but the excessive wear was due to the fact that we operated much of the time in fine sand, which worked in through the air-cleaner.

Earth Removal

The records show that the actual cost of moving earth with the tractor outfit on wagon work during the past season averaged about 1.5 cents per cu. yd. less than with the horse-drawn outfit. These figures are no doubt disappointing to those who expect the tractor to make a better comparative showing but the tractor outfit was operating largely on jobs where the machines could not work at their maximum efficiency at all times. Part of the time they worked in very loose dry sand, freely interspersed with boulders, while the horse-drawn outfit encountered very little rock during the entire season and was operating in soil that was ideal for an elevating grader. If the same outfits were placed on work where the soil conditions were the same, the actual cost of moving earth with a tractor outfit would be from 3 to 4 cents per cu. yd. less than with the horse-drawn machine.

Motorization of earth-loading machinery has been accomplished. The next step is to motorize the earth-hauling equipment in such a way that material can be moved more cheaply. Much time and money have been spent but no machine thus far designed for this purpose seems entirely practicable. Gravel hauling has been revolutionized by the motor truck; so, why not apply mechanical power to the moving of earth?

Many grading contractors are prejudiced in favor of horses for all purposes. After 2 years in business I decided that it might be well to adopt the plan of trying anything once. I am satisfied thus far; so much so that I shall add tractors to my outfits as fast as conditions will permit, being firmly convinced from experience that we are only beginning to realize the value of tractors on construction work.

I believe the contracting field offers the greatest opportunity for engineers in the history of the Country. Highway construction has only just begun and railroad work will be opening up again within a short time. The number of contracting firms in this line will be wholly inadequate. The engineer who enters the contracting field is not sacrificing his prestige; rather, he is adding to it. The day of the old-style, hard-boiled contractor is passing and the educated man is taking his place. There was a time when the man bidding for a job worked out his proposal by rule of thumb, and then wriggled and squirmed his way through the job, trusting that the "customary settlement" would bring him out all right in the end. Much litigation resulted. Now, a proposal must be made intelligently, with a real knowledge of costs, and the contractor is paid on the basis of work actually performed. The engineer knows how the work should be done and will do it, and he will do it in the most economical way, because the education of the engineer is always toward economy and efficiency. I do not mean to say that all engineers will make good contractors. There are many who are lacking in initiative or who have no confidence in their own ability; but the confident, practical engineer can put his talents to better use as a builder than in any other way. He can not only plan, but he can carry out such plans to completion and have the supreme satisfaction of knowing that the work is well done.

THE DISCUSSION

CHAIRMAN W. G. CLARK:—I am sure it has been of great interest to hear the practical side of road building from a man who has been through it. It is easy to theorize on how a thing should be done, but the man who has to go through it and do it is the man who really knows the thing from one end to the other.

L. C. HILL:—What grading is done to prepare the subsoil for carrying the loads that motor trucks impose on the roads? As I understand it, the roads under discussion are principally gravel roads.

R. C. SCHOEN:—The work is grading entirely. We have done gravel work, but my paper pertained almost entirely to grading and not to gravel work. We build right up from the virgin soil.

MR. HILL:—Is nothing done other than grading? Is nothing done, for instance, in the way of special drainage, laying of tile to drain the road, or laying of concrete?

MR. SCHOEN:—Wherever special work in the way of drainage is necessary, it is done; we have laid tile in many places designated by the highway engineer, or con-

structed special side-ditches, and the like, but that is all in connection with the road itself to prepare the road-bed for gravel.

O. W. YOUNG:—Where do the truck and dump-body equipment available today fit in with Mr. Schoen's ideas of efficient hauling? I believe he stated that this phase of the work has not yet been motorized satisfactorily.

MR. SCHOEN:—I spoke only of hauling earth. The motor truck is satisfactory for hauling gravel, but the motor truck with a dump body will not work in hauling earth because the earth is carried out over a loose dump down over the end where the wheels do not get traction, and a different type of vehicle must be used. On hard-surfaced roads the motor truck cannot be excelled, but the roads are not always hard-surfaced.

My attention was called recently to a new dump wagon. It is a 6-yd. all-steel wagon, weighing about 6500 lb. empty. It is designed to be hauled behind a small tractor, say about 15 hp. If such a wagon can be made practicable, I think it is what we need to motorize our hauling equipment.

I tried the Maney four-wheel 1-yd. scraper in 1919 in North Dakota. I used at first a 16-hp. steam engine for loading. The engine loaded the scraper all right but wrecked three or four men who happened to be on the machines. It requires a man to unload each machine. If you hit a rock it is liable to throw the man off on his head. This steam tractor was continually breaking down, and I abandoned it. Then I began loading with five heavy horses and found that was too expensive; I could not afford to have five horses loading and four horses plowing, so I went back to the elevator and wagons. I think that a machine like the Maney four-wheel scraper, built heavier and designed to be hauled behind a small tractor, would be a good machine for handling loose earth. I think the Maney four-wheel scraper is not practicable for hard work.

MR. YOUNG:—During the war, track-layers, I think they called them track-adapters, were applied to trucks. Although not used extensively they were operated successfully, at least experimentally. A track-laying unit was applied to the axle of the truck. Does Mr. Schoen consider that this traction equipment might fulfil the fundamental requirements of hauling?

MR. SCHOEN:—I think you are on the right line. What we want is some sort of machine that can easily approach the elevating grader to pick up its load. While it is under the elevator, traction for any kind of truck is adequate as a rule, but when away and going down on the loose, soft dump, the traction is not adequate.

MR. YOUNG:—Steering probably would be the problem then. On loose ground the front wheels of the four-wheel truck would be difficult to control.

MR. SCHOEN:—That would not bother much; it is the traction. A truck will sink into the loose earth when driven over it to dump a load over the end. A team would be necessary to pull the truck out.

MR. YOUNG:—Traction would overcome that.

MR. SCHOEN:—A track-adapter could be fitted to these trucks in a practical way, which would be all right.

A. W. SCARRATT:—A truck somewhat along this line, the Lombard truck-tractor, is on the market and is built, I believe, in Maine. It is a kind of cross between a truck and a tractor. Instead of having the usual round wheels at the rear end it has a pair of track-laying wheels. It was developed primarily for logging operations in the northern part of the Country and is not very different from the one Allis Chalmers worked on about 6 or 7 years ago. Another company at Eau Claire builds a logging engine that I think could also be used for this work. I think that the trade name of this machine is the Centipede.

C. O. WOLD:—There is another that I think would probably come closer to what you have in mind, because the Eau Claire and the Allis Chalmers machines, especially the latter, are very large. I think the Allis Chalmers weighs about 15,000 lb., perhaps more. There is one made in New York State called the Lynn tractor, of which a number have been sold in New York and also in northern Maine. It is often used as a tractor for small 8-ft. graders. There are about 50 of our machines working behind that truck now in road building.

MR. SCHOEN:—A thing that must be considered is the possibility of operating a dump-body.

MR. WOLD:—A truck equipment of that kind has to be made in such a way that it can come to the elevating grader from behind. The cab, as usually put on such a truck, would be in the way.

MR. SCHOEN:—Not at all.

A. W. BENSON:—My scheme of handling the dirt and the gravel is by a trailer to be hauled behind a tractor. The great difficulty of doing this is in controlling the loads on grades. We think we have solved this problem by adopting a rig by which we carry a large tonnage not on four wheels, but divided into small units. For this we have developed a two-wheel rig, that can be controlled by air. We have made experiments showing that with a 30-hp. tractor we can haul 16-yd. up an 8-per cent grade. That, I believe, is the record with such a load under control.

OBITUARY

EDMUND LEAVENWORTH FRENCH, manager of the Halcomb & Sanderson Bros. Works of the Crucible Steel Co. of America, died Aug. 31, 1922, at his summer home in Tully Lake Park, near Syracuse, N. Y., aged 51 years. He was born Oct. 12, 1870, at New York City. Following his preliminary education he attended Syracuse University and was graduated from that institution in 1902, receiving the degree of Bachelor of Science. He then spent 2 years in attendance at the Royal School of Mines, Freiberg, Germany, specializing in metallurgical engineering subjects.

Mr. French was successively chemist, metallurgist and manager of the Halcomb & Sanderson works subsequent to the completion of his technical education and, in addition, was in charge of sales of automobile steels for the Crucible Steel Co. of America during 1905, 1906 and 1907. He was elected to Member grade in the Society, July 23, 1910.

GAGE STEEL STEERING COMMITTEE

A MEETING of the Gage Steel Steering Committee has been held at the Bureau of Standards for the purpose of outlining in detail the first work to be undertaken. It was decided that a special research operator, proceeding under the supervision of the Committee, would be required for the successful prosecution of the work in view, and that the first series of experiments should largely form a study of the effects of the rate of heating on the dimensional changes in hardening and a comparison of the resistance to abrasion of the various steels previously selected by the Committee.

The Storage-Battery as a Mechanical Problem

By Clarence W. Hazelett[1]

Cleveland Section Paper *Illustrated with* Photograph

After stating his belief that the storage-battery is a mechanical and not an electrochemical problem, the author reviews some of the storage-battery improvements of the last decade and comments upon the advantages of using thinner plates as a means of increasing their number in a given size of cell and so holding the active material in the positive plates. Plate and separator construction difficulties are enumerated and discussed in some detail, a photograph being shown of a battery having unusual characteristics that are described.

Questions relating to storage-battery capacity and length of life are considered, inclusive of effects due to temperature, initial amperage, discharge rate, amount of active material used, charging rates, internal battery resistance and voltage.

NO unusual improvement has been made in the lead storage-battery since the discovery of the pasted plate. The principal improvements have been mechanical in nature, and I believe that the storage-battery is a mechanical and not an electrochemical problem. Within the last decade we have had the iron-clad type of battery developed in which the mechanical construction is such as to hold the active material in the plates, and the alkaline cell in which materials are employed that will allow a better mechanical construction. Several times the theoretical amount of material actually used in its discharge is present in the plates of a storage-battery. This leads us to think that it is possible to make use of more of the material. It has been proved that the action on the storage-battery plate does not penetrate more than 1/32 in., even at commercial rates of discharge. To-day, plates ⅛ in. thick are practically standard. If it is possible mechanically to make thinner plates and take care of the other difficulties at the same time, it seems that some real improvement might be made.

The life of all storage-batteries is particularly dependent upon holding the material in the positive plates, in preventing mechanical breakdown, short-circuits, the cutting through of separators and other mechanical failures. A pronounced tendency toward thinner plates in storage-batteries has existed for the last 10 to 12 years. Plates ¼ in. thick were standard 15 years ago, but that thickness has been decreased gradually, 1/64 in. at a time, until both starting and vehicle batteries have been standardized, practically, and use plates ⅛ in. thick. The principal reason for this change has been the increase in capacity per dollar of cost, but that is not always the safest rule to follow. The capacity per pound of lead and active material also increases rapidly with a decreasing thickness. The tendency has been to use the same number of plates when their thickness was cut down, which did not decrease the capacity materially but shortened the life of the battery. If abused, the thin-plate battery will fail generally through buckling and short-circuiting in connection with standard construction, but for equal amounts of active material, the active material itself is longer-lived in a battery having a large number of thin plates.

If twice as many plates of one-half the thickness are used, the amount of surface will be doubled, the current density on charge and discharge will be reduced one-half and the heating effect will be decreased considerably; the rate of sulphation on discharge will be decreased and many advantages in charging and discharging will result from these characteristics. Heating is the principal cause of plate buckling and separator destruction; it will soften the active material in the positive plates and, if carried beyond 130 deg. fahr., will almost destroy the negative-plate capacity. So, the thin-plate active-material is longer-lived when used in the same quantity as in thick plates. The amount of gas given off per unit of surface is less, and the erosion of the material from the plates that is due to the gas bubbling up is very much lessened. The thin-plate battery has been tested by engineers of the largest companies and it has been found that it almost always wears out from buckling and short-circuiting, which are mechanical failures. On discharge, a thin-plate battery having a large number of plates does not heat up so much as one having thick plates. The reason is the lower internal resistance when the number of plates is increased, or, in other words, when the number of circuits in multiple is increased. The performance and life of a storage-battery should be improved by thinning down the plates, if this can be done from a mechanical standpoint.

When a battery gives the high capacity obtained by using the thinner plates, the battery is not charged as often in vehicle service. The principal damage to a storage-battery in service is done at the end of the charge when the gassing and heating occur. The plate material is worked more uniformly if a working thickness of the plate of 1/32 in. can be approximated. The unnecessary material in the ordinary storage-battery plate is used as a reserve while the surface material is worked off. In a new battery the superficial material is working and the interior is inactive when the plate becomes old, the outer material is in the bottom of the jar, while the cores of the plates are active. Several practical methods are used for holding the active material in the plates. It is customary to use a rubber separator in contact with the positive plates of vehicle batteries, which assists in holding the material in place. It has been shown that there is a large increase in the length of life by using the rubber separator but as soon as the surface of the plate has been worked off, the core washes out and does not produce any large increase in life. If we save the surface of the plates we save all. In the case of the iron-clad storage-battery, two to five times the ordinary life is obtained by holding the active material in the positive plates. That is the secret of obtaining long storage-battery life. The active

[1] M.S.A.E.—President, Hazelett Storage Battery Co., Cleveland.

material can be held in place, and the manufacture of thinner plates is purely a matter of manufacturing ability.

Plate and Separator Construction Difficulties

It is difficult to construct equipment with which plates 1/8 in. thick can be cast successfully. It is an heroic task to make equipment that can cast the 3/32-in. plates, which are used entirely by one manufacturer, without greatly increasing the percentage of antimony. Antimony is put in because it makes the metal more fluid and is necessary to give stiffness to the grid, which prevents it from growing. The handling of a large number of thin plates is expensive and it is difficult to paste thin plates in ordinary practice because this must be done from both sides. The plates become light, they will not lie on the table when being pasted and there are other very difficult complications, such as the holding of the pellets in a thin grid through the handling processes in the current method of manufacture.

The view that the need is for a large amount of surface, an increase in the number of plates, a decrease in their thickness, the holding of the active material in the plates and the development of the mechanical construction so that it will withstand the abuse to which batteries are subject, resulted in the battery shown in Fig. 1, which has some unusual characteristics. It required the development of a system of making cast lead sheets because rolling-mill lead will not work, and the production of a cast-lead antimony alloy sheet at a low cost. The sheet is approximately of No. 20 gage and is made in strips several thousand feet long. It comes from the machine at the rate of 70 ft. per min.; it is then fed into a punch-press and grids are stamped from it continuously. Practically no skilled labor is necessary and the material comes out as one would expect it to come from a machine.

It then becomes necessary to develop a separator to hold the active material in place. Wood veneer 1/16 in. thick was tried first. This worked very satisfactorily in an electric car and no difficulties developed in the batteries. However, it is difficult to treat a wood separator. Wood veneer 1/16 in. thick could be treated by any satisfactory factory process only with difficulty. Further, the veneer separator did not fill the space between the plates fully. The failures of others indicated that if an attempt were made to hold the material in the positive plates it must be held hight in the grid. If it is not held tightly, it will wash off, begin to sulphate and swell. To avoid this long-grained wood was rubbed up on an emery wheel; this split off the fibers, they were treated, and laminated sheets were made from them. This process resulted in a laminated separator 1/16 in. thick of pure wood fiber that can be treated more easily than veneer. It is made into sheets and is mechanically perfect. These separators swell so as to fill the space between the plates absolutely and hold the active material in the plates as is desired; they hold sufficient electrolyte and it is surprising what a large number of cubic inches of electrolyte they will absorb. Regarding porosity, if one of these separators be dried out and a drop of water placed on one side, the moisture will penetrate entirely through the separator in 5 or 6 sec. A battery is never discharged within 5 or 6 sec.; so circulation need cause no anxiety. Several mechanical advantages result from using such a separator. In ordinary storage-battery construction it is not possible to extend the separators down to the bridge and, if they are extended beyond that, they will split. This laminated separator material simply folds over, the separators are extended beyond the bottom of the plates, rest on the bottom of the jar and give added protection; further, wood fiber separators will swell and fill all the space allowed them. If allowed to do so, it is likely that they would expand another 1/32 in., but as that is unnecessary, it is preferred to have them more compact. The wood-fiber separator acts like a wick, draws the electrolyte up and prevents any damage to the plates; it will hold the electrolyte between the plates so that the excess can be poured from the battery, a discharge can be made and the rated capacity obtained at any rate of discharge desired. That feature is very desirable in such portable outfits as miners' lamps or in airplane work.

Observation of the oldest of these cells that have been made indicates that the active material does not and can-

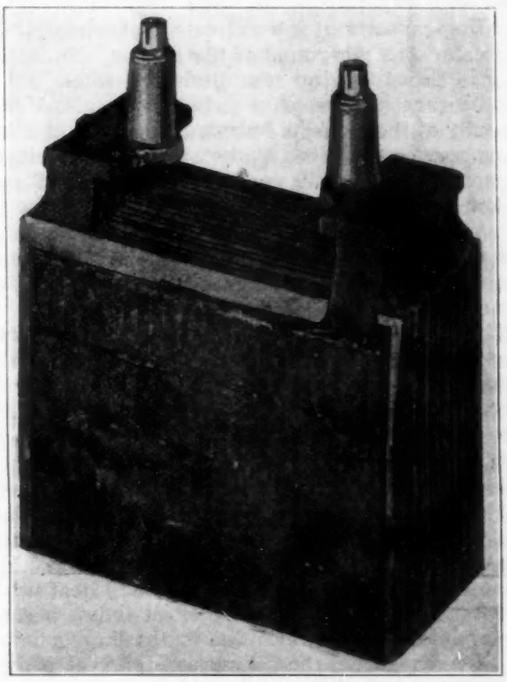

Fig. 1—Storage-Battery Element in Which Wood-Fiber Separators Are Employed between the Plates

not escape from the plates. The insulation is dependable as it now stands because it extends beyond the plates. An important improvement has been made wherein the four edges of the separator are dipped in a hardening acid-proof mixture, which produces an indestructible frame about the entire separator, thus preventing any damage to them. The positive plates are pushed to one side, the negative plates to the other and the projection on the vertical edges is 1/4 in. or more. The fit of an element in the battery jar is very important. Jar breakage in motor vehicles occurs because the jar does not fit snugly in the tray, or the element does not fit snugly in the jar. If the element can move in the jar, a cracked jar is likely to result. These elements fit tightly, will hold their position and come out in good condition after indefinite use.

This wood-fiber separator is not subject to mechanical chafing. In the usual construction, when an ordinary plate buckles the vibration and the consequent chafing action cause the plate having the pressure to wear through and produce a short-circuit. Practically all of the failures of batteries are caused by buckling and short-circuiting and by the erosion of the material in the plates. This battery uses approximately double the number of plates that are provided ordinarily in a storage-battery. An element consisting of 13 plates replaces the 7-plate standard. The 11-plate standard element is replaced by a 20-

plate element in this battery and, because there is approximately double the amount of surface, an unusual capacity per pound and per dollar is expected.

Storage-Battery Capacity and Life

Storage-battery capacity in ordinary automobile practice is important primarily at low temperatures and at the current value required for initial movement of the engine parts; that is, the break-away current. Initial available current is approximately proportionate to the plate surface exposed. With the type of battery under discussion this initial available current per pound of plate is 2 to 3 times that obtained from batteries having thicker plates, both cases being at +10 deg. fahr. The corresponding capacity at low rates is approximately 50 per cent greater on a per-pound-of-plate basis. No laboratory work has been done on low discharge rates, but other recent observations seem to indicate a marked increase in capacity at the low-rate discharge used for ignition and lighting service also; that is, the increased capacity seems to be something like 50 per cent per pound of plate at very low rates of discharge and at a 5, 6, 7, or 8-min. rate. At the 20-min. rate of discharge the capacity per pound of plate is increased approximately 100 per cent. Less active material and a decreased plate-weight are used in these batteries.

Ordinarily, if a battery plate has a flat side, when it begins to gas two volumes of hydrogen come from the negative plate to one volume of oxygen, and the flat side of the separator is against the negative plate. The gas escapes without difficulty, and it does so in a somewhat similar manner from the battery under discussion. The charging rates it requires while in a discharged condition allow the usual proportion of amperage but, as the battery becomes charged, this amperage should be cut down. The gas does not escape as rapidly, even though the battery has twice as many plates, and it will heat up about as is usual, but the total heating effect is less because of the lower internal resistance due to the large number of plates. On discharge, the voltage is higher at given current rates, particularly if the battery is shaken somewhat or allowed to stand after charge until the gas has escaped more completely. The internal resistance of the battery referred to seems to be 65 per cent of what is usual and that results in a higher efficiency. The separators do not clog or disintegrate. It was difficult to form plates with the separators in place between them, especially when using those made of veneer, without causing trouble at that time, but this difficulty was overcome. At any period in the battery's life, the separator does not clog and comes out as clean as when put in. It does not disintegrate, for the material has no place to be deposited. The separators are made out of the same material as is a wood separator, and there is no mechanical chafing action on them. In reference to whether the gas given off at the positive plate attacks the separators, no such effect on a rib of a wooden separator occurs, as is evidenced by a 2-year experience with the battery. Tests were made some time ago on a vehicle cell. After approximately three times the expected life, an examination of the cell revealed about ¼ in. of sediment in the bottom. The capacity of discharge was still 12 per cent above ordinary and all the material was in the plates. The voltage on discharge was high. The material came out with the separators when the plates were opened, and that cell had been abused greatly. No difficulty has been experienced with mechanical disintegration of the fiber separators since the use of the frame of acid-proof material.

The ability of the separator to hold the electrolyte within itself results in another advantage. The elements are charged completely and shipped to the service-stations. All that is required then is to insert the elements in the jars, pour in the electrolyte, seal the battery and put it to work. The elements do not dry-out. The separators hold the electrolyte and the elements do not discharge any more than if in a battery jar. The element is wrapped in oiled paper. This allows the service-station to keep elements in stock. If a customer wants a rebuilt job and insists on having one cell repaired, only about 20 min. is required to repair a cell, and about 45 min. to rebuild an entire battery. That allows service-stations to give very rapid service to customers. A customer can come in with a battery and go out in the time required to put in a loan battery or take one out; or he can have a dead cell replaced within 20 min.

When an engine is started with a battery the voltage falls and causes ignition difficulties. The electric starter should give the engine a good kick, and it is necessary that the voltage stay up. This requirement is met by having a battery of this type with a large number of plates.

THE DISCUSSION

C. T. KLUG: In making a quick change at a service-station, is the element put into the battery without having been recharged?

C. W. HAZELETT: The element does not require charging unless it has been stored on the shelf. The action on the plates is exactly the same as if the element had been installed in a battery. The electrolyte is held within the separators, instead of being present between the plates.

W. R. STRICKLAND: What space is necessary as a settling basin?

MR. HAZELETT: A ⅛-in. space is ample. A dusty appearance on the bottom of a jar is the only indication of sediment. The oldest successful battery of this kind was built in October, 1919, and was returned just recently; the battery case was completely gone and the bottom was out, but the amount of sediment was very slight.

MR. STRICKLAND: In what type of battery would a settling basin of ⅛ in. be needed?

MR. HAZELETT: In a vehicle battery.

MR. KLUG: With the separator pressed up so tight, how does the sediment descend?

MR. HAZELETT: The sediment does not go down; it is only lead that has been dissolved and that is reprecipitated. It is the same as the moss on the top of the negative plates.

MR. KLUG: What is the recuperative power of this battery?

MR. HAZELETT: The recuperative power is rapid, but very little current is delivered after the first discharge.

MR. KLUG: What is the effect on this battery of holding the starter of an automobile in service too long at a time?

MR. HAZELETT: The battery will run the starter longer than usual and no ill effects are produced.

MR. STRICKLAND: How many times can the battery be discharged and recharged?

MR. HAZELETT: A large number of times, I dislike to make any statement regarding the life of a battery because the length of life of any battery is an open question. Judging from experience and all available information, the indications are that at least double the ordinary life of a battery can be expected.

A MEMBER: What is the efficiency of this battery?

MR. HAZELETT: About 88 per cent.

A MEMBER: What are the possibilities of using a hard-rubber case for such a battery?

MR. HAZELETT: The hard-rubber case has been tried out; it was a failure on account of its high cost and because it was easily cracked after it had aged. When one crack developed, the case had to be thrown away. The demand for a good substantial storage-battery case is unlimited. Every firm in the country needs something better than the standard wooden box. Much experimental work is being done along that line.

A. M. DEAN: What is the maximum mileage obtainable on good roads from an electric-vehicle storage-battery that requires the same space as is usual, after having had a complete single charge; that is, what limitation is there on such a battery for use on an electric vehicle?

MR. HAZELETT: With some of the lighter electric vehicles 135 to 140 miles should be obtained when driving in the running notch. The type of car, the kind of tires, the weather, the kind of road and the driving notch used make a difference. In climbing hills there is almost no dropping off in the battery capacity because of the high rate of discharge. My own car pulls 100 amp. at times.

A MEMBER: The battery being so well filled up with the separators, how long a time is required, after starting, to charge it so that the electrolyte gives a proper specific-gravity reading?

MR. HAZELETT: In general, about 2 hr. after the voltage indicates full charge. When this kind of a battery discharges at a high rate, hardly any drop in the specific-gravity reading is noticeable. The specific-gravity reading does not follow the condition of the cell very rapidly. During charge, hardly any increase of specific gravity can be noticed until the cell begins to gas. The electrolyte is at a low specific gravity at the beginning of the charge, and it has a tendency to increase in specific gravity as it is charged. The electrolyte of high specific-gravity then settles downward in the cell of its own accord, and no increase of gravity occurs at the top of the cell until the electrolyte becomes thoroughly mixed on account of gassing.

A MEMBER: When a repair unit is shipped, is any allowance made for swelling of the separators after they are put into a cell? Is the element soaked to a maximum before being shipped?

MR. HAZELETT: The elements are delivered just as they are constructed in the factory; the separators are so uniform that the elements have swelled as much as they will swell and all that is required is to bring an element to its proper dimensions by squeezing it. The element is somewhat like a cushion; it does not break a jar when pushed down and yet it does not move with respect to the jar.

A MEMBER: Is there any less danger of breaking battery jars from freezing with this type?

MR. HAZELETT: I do not know; the expansion would be absorbed by the separator to some extent.

A MEMBER: To store this battery in cold weather, what should be done with it?

MR. HAZELETT: It should be stored in a warm place.

W. C. KEYS: What kind of wood is used in making these separators?

MR. HAZELETT: We prefer to use a long-grained wood, such as cedar or cypress. It withstands the action of sulphuric acid better. The process is somewhat along the lines of making paper.

MR. KLUG: Are these separators built up in layers?

MR. HAZELETT: Yes, they are laminated to increase the dependability by eliminating flaws. There is not so much lead in this battery as is ordinarily the case and a 6-volt battery is lighter than is usual by 11 lb. When the batteries are sent out the specific gravity is 1250 to 1260. That provides sufficient acid for an adequate capacity, and the cells will last longer if worked at a lower specific-gravity.

A MEMBER:—How is a battery plate made?

MR. HAZELETT: The grids are pasted, practically by hand, although it requires little hand labor and does not require a machine. One man can paste 10,000 plates per day. It is necessary to apply paste only on one side of the plate. The sheet from which the grids are punched is cast. Handling lead under pressure destroys its crystalline structure. Only a normally cast alloy will work satisfactorily.

H. G. WELFARE: A battery ordinarily has 11 plates and the battery described uses 20; why is one negative plate left off?

MR. HAZELETT: The quantity of plates that fits the standard-sized jar snugly is used and the number happens to be 20. The omission of 1 plate in 20 makes only a 5-per cent difference, assuming that this decreases the capacity of the battery an amount equal to the capacity of an entire plate, which of course is not true. The ordinary battery has a plate of standard thickness on the outside of each element and that plate works only one-half way through; so, there is one-half a plate on the outside of the two sides of each element that is not working, the equivalent of one entire plate per cell. That entails a loss of about 9 per cent. Since the plate in this battery works all the way through, that 9 per cent is not lost.

MR. KEYS:—If, as stated, this battery carries more electrolyte than is usual and has less clearance at the bottom, where does it carry the electrolyte?

MR. HAZELETT: Actually within the separators; in an 11-plate battery there would be 19 separators and the volume of acid is above the ordinary amount.

A MEMBER: If this battery were applied to a solid-tired motor-truck, would it be necesary to go to extreme trouble in mounting it, supporting it on springes, for example?

MR. HAZELETT: It is advisable to do that when mounting any battery, but this type is less affected by vibration.

C. H. PRATT: I understand you to say that the electrolyte will not freeze, but when this evaporates and the solution is replenished with water, what chance has the water to mix with the old electrolyte?

MR. HAZELETT: When water is put in, it will mix only as rapidly as will two fluids of unequal density, unless the battery is charged. The filling of the cells with water and putting the battery out in real cold weather is not recommended.

A MEMBER: Does the same amount of evaporation occur as is usual?

MR. HAZELETT: About one-third the usual amount of water is needed to compensate for evaporation. However, when any battery is charged, a given number of ampere-hours will decompose a given quantity of electrolyte, but as this battery develops less heat, the evaporation is not great.

A MEMBER: What is the rate of heating on this battery under high charging rates?

MR. HAZELETT: Before the gassing point is reached, the temperature does not increase appreciably. Constant-current charging of a set of battery cells at an ordinary voltage will not heat any battery to amount to anything. This battery absorbs the current satisfactorily without increasing the temperature above the limit and it absorbs current at a tremendous rate when the battery is first put on charge. After it is charged completely at the normal

charging rate, the battery will lag about 10 deg. behind usual temperatures.

A MEMBER: This battery having more plates, is it possible to use it for lighting-plant service?

MR. HAZELETT: Yes, it works well in lighting plants. It is not necessary to worry about charging rates or overcharging.

A MEMBER: What is the effect of over-discharging on the plates?

MR. HAZELETT:—If this battery is allowed to discharge for a long period of time and is charged, the charging voltage is high but the battery comes right up because the plate material is accessible to the electrolyte and the crystals formed are not large for the reason that the separators are in contact with the plates.

A MEMBER: Is not the active material broken down as a result of this practice?

MR. HAZELETT: No. The ampere-hour capacity can be decreased slightly by making the material less active, but the voltage will be adequate under those conditions and the battery will work satisfactorily and not decrease to an extent sufficient to prevent it from functioning in ordinary service.

A MEMBER: In charging, will the gas emitted from the separators produce a rising of the level of the electrolyte?

MR. HAZELETT: The rise in level is about the same as is ordinarily experienced. Gas dissolves in the electrolyte to some extent and thus increases the level of the electrolyte during charging.

A MEMBER: What is the 20-min. discharge rate on a battery of the size used on a Ford car?

MR. HAZELETT: The 20-min. discharge rate is 125 to 130 amp.

A MEMBER: What is the 5-sec. discharge rate?

MR. HAZELETT: It approaches the ratio of plate surface; the 5-sec. discharge rate would be 75 to 80 per cent above the usual result. The capacity does not increase in proportion to the plate surface on low rates of discharge; at high rates of discharge it becomes a plate-surface proposition. The plates in this battery can be buckled the same as all storage battery plates, but they can be straightened by pressing one's finger against them.

FUNDAMENTALS OF ENGINE DESIGN

(*Concluded from p.* 332)

gas velocities than is usually supposed, without any loss of volumetric efficiency, in which case turbulence looks after itself.

A MEMBER:—I believe that turbulence has nothing to do with it. If one blows smoke into a test-tube, puts a plug of cotton in the end and pushes it up, there is no mixture whatever. If the plug is pulled down turbulence is produced.

MR. POMEROY:—I think there is no doubt that gas velocity, as such, has a pronounced effect upon turbulence in spite of the experiment described. Sir Dugald Clerk made experiments many years ago by taking indicator-diagrams from a gas engine that had been allowed to rotate for a few revolutions with the ignition off and the inlet and exhaust-valves closed, the ignition and valves then being put into commission and a diagram taken of the consequent working cycle. The result showed that whereas maximum pressures of some 400 to 500 lb. per sq. in. would be produced in the ordinary way with a characteristic gas-engine diagram, when the explosion was delayed sufficiently to allow turbulence to die down, the explosion pressure was very low indeed while the resulting diagram had none of the characteristics previously obtained.

JOHN MCGEORGE:—I gather that the poppet-valve engines are most efficient when they are new, but that a slide-valve engine is easier to work with. Does that mean that in the beginning the poppet-valve engines are much more efficient and that their efficiency becomes reduced, while the slide-valve engines continue their efficiency unimpaired?

MR. POMEROY:—My experience is that from the viewpoints of economy and power a well made poppet-valve engine will maintain these qualities fully as well as engines of the slide-valve type. In fact, it seems difficult to believe that the same volumetric efficiency can be obtained with the slide-valve as with the poppet-valve engine, owing to the necessarily higher internal-temperature reducing the volumetric efficiency due to the heating of the incoming gas. Experiments on slide-valve engines show a much larger proportion of heat rejected to the exhaust than is the case with poppet-valve engines, thus clearly indicating the higher internal cylinder-temperature.

A MEMBER:—Is the fuel in Great Britain of a better grade than we have in the United States? I am told that American cars fitted with American carbureters operated better in Great Britain on a mixture of three-fourths gasoline and one-fourth kerosene.

MR. POMEROY: — The English gasoline is of better grade than the American. The poor quality of gasoline in America has done much to hasten the development of the gasoline engine.

A MEMBER:—What system of lubrication was used for the engine in which the babbitt bearings were installed?

MR. POMEROY:—Forced-feed lubrication with a pump of $\frac{7}{8}$-in. bore and $\frac{3}{4}$-in. stroke, running at camshaft speed, was used. The delivery of this pump at 1000 r.p.m. of the engine is about $\frac{1}{2}$ gal. per min., the important thing being to supply plenty of oil rather than worry about the oil pressure itself, which in this case is about 15 lb. per sq. in.

MR. MCGEORGE:—I have heard the statement that it is better not to use any oil-grooves in forced-feed lubrication.

MR. POMEROY:—That is correct for forced-feed lubrication. The oil, being under pressure, will distribute itself without any grooves.

A MEMBER:—Do you endorse the floating piston-pin?

MR. POMEROY:—The floating piston-pin is advantageous because the wear is distributed over its entire surface and no restraint is imposed upon the expansion of the piston itself.

MR. MCGEORGE:—Do you favor the slitting of the skirt of the piston?

MR. POMEROY:—The piston having a slit skirt certainly allows the use of very small clearances and, given correct general design, it completely eliminates piston slap, the well known hindrance to aluminum-piston applications. It involves, of course, having the head partly separated from the skirt so that cooling takes place through the contact between the rings and the cylinder walls, which is, however, probably where the majority of heat escapes in any design of piston.

Automotive Equipment in Road Construction

By A. C. Godward[1] Minneapolis Tractor Meeting Paper

THE plan adopted by some contractors of renting machinery to the project to assure a return on the equipment, regardless of the status of the rest of the work, involves the discussion of methods of determining depreciation, rental charges and the ratio of operating costs to fixed charges. Comparison is made of the author's system with that used by the Associated General Contractors. The costs of operation of a dump-truck, a caterpillar tractor and a steam-shovel were investigated and the results tabulated.

IN automotive equipment, the vital things are depreciation, maintenance and repairs. In the brief time allotted to me it will not be possible to cover this subject fully. I have chosen particularly the economic side of automotive equipment, to show the value of records of operation, maintenance and repair, to the owner, the designer and the manufacturer. Twenty years ago we thought only of mules and manpower. I remember the first tractor I had was a great disappointment. The tractor today is a joy forever. Through all these years as a personal hobby I have kept records of performance, cost and depreciation; they have shown how the designer has gradually eliminated the undesirable features and made automotive equipment an economic working unit. That being my hobby, it is naturally the line along which I wish to speak.

As engineers, we approve the statement of James J. Hill, the empire builder, that in modern civilization the engineer is the creator. It was not entirely the hope of pecuniary gain but the instinctive desire to create for the welfare of our fellow beings, that drew us into this our chosen profession. Among the members of this diversified calling the automotive engineer ranks high in ingenuity, tenacity and ability in the creative art. His work in a few years has changed the mode of transportation and the mode of living.

By revolutionizing the methods of transportation the automotive engineer has made the highways of yesterday useless, but in return he has given us equipment by the use of which we can economically construct the roads anew. We who during the greater part of these 20 years have devoted our energies to the construction of roads and highways have watched with interest his progress, we have sorrowed at his failures and rejoiced at his successes, and now, more appreciative than the rest of his friends, we bear glad and whole-hearted tribute.

In automotive equipment, the proof of design and mechanical construction is in the operation. Contractors as a group were as vitally interested in the development as were the designers and the builder, and being constantly at the operating end they were in a position to observe and record accurately the performance of the equipment and to give constructive criticism. A few with limited technical knowledge appreciated their position and responsibility and assisted the designer and the serviceman in eliminating faulty features. To them much credit is due. Experimentation, the creation of new alloys, the design of new bearings and appliances, the elimination of unnecessary parts and weight, standardization, better ignition, carburetion, transmission and balance and all the other improvements in equipment and accessories with which we are familiar today were continued until at last the many types approach perfection in design and application.

[1] Chief engineer, Minneapolis Park Board, Minneapolis.

Depreciation and Rental Schedule

Progress automatically eliminates the contractor who will not see. Today contractors manage their equipment investment in an efficient and economical manner and designers and builders can procure reliable and accurate statements of performance, detailed as to quality, quantity and cost. Competent public officials have learned to treat pieces of equipment as individuals and to study them as economic units. There is now something more than intangible kicks upon which to base study and design. The day is gone when equipment is bought as a one-job investment or at the whim of a public official regardless of economic principles. The trend of the times is shown by the development by the contractors' association of a schedule of depreciation and rental, and by the tendency of contractors to rent the equipment to their own projects at a predetermined rate per hour or day so as to assure a sufficient return of all costs regardless of the status of the project. Road construction is a continuing business and equipment must be designed and purchased accordingly.

Many of the municipal contractors today are following the plan mentioned; instead of letting their machinery go with the job if the job goes wrong, they let the job go where it will but assure a return on that piece of equipment sufficient to maintain, repair and put it into condition for the next job when they are fortunate enough to get one. The Associated General Contractors adopted a schedule in July 1920 predicated upon an expense divided into seven parts. This was made a basis of rental and is illustrated by a typical case shown in Table 1, on the assumption of a 6-year useful life.

TABLE 1—TYPICAL DEPRECIATION AND RENTAL SCHEDULE; LIFE, 6 YEARS

Items	Percentage of Original Cost
Average Annual Depreciation	12.5
Equivalent Annual Interest	4.0
Shop Repairs	6.0
Field Repairs	4.0
Storage and Incidentals	3.5
Insurance	1.0
Taxes	1.0
Total	32.0

Based on 8 months of operation this total of 32 per cent, as shown in Table 1, is a rental per month of 4 per cent of the original capital investment. The average depreciation is based on the economic life of a machine that is supposed to end when the value of the machine

shall have depreciated to 25 per cent of the original cost. The annual depreciation is 75 per cent of the original cost divided by the number of years during which experience has shown it can be expected to give service. The equivalent annual interest is based on the prevailing rate each year on the depreciated value. The other charges are self-explanatory, a division being made between shop and field repairs for the purpose of computing different terms of rental. Nearly 100 items of equipment enter into consideration and the annual depreciation varies from 75.0 to 7.5 per cent, depending upon the type of machine and the class of work.

In municipal work we began the practice years ago of considering all equipment requiring an operator as an individual unit, renting it to the project on which it was being used at a fixed cost per hour and at a rate to assure a return sufficient to cover all fixed and operating costs and create a small reserve for emergencies. We based the rental charge on nine instead of seven component parts, five of which were fixed charges and four were operating charges. The fixed charges are (*a*) average annual depreciation, (*b*) equivalent annual interest, (*c*) storage and incidentals, (*d*) taxes and (*e*) insurance. Depreciation was included as a fixed charge regardless of hours of operation per year, as improved designs make obsolescence a deciding factor. The operating charges are (*a*) shop repairs and overhaul; (*b*) field repairs; (*c*) operating cost while employed; and (*d*) cost of maintenance, which consists of overtime work of adjusting, oiling, greasing and the like. The cost of time lost while equipment is on a project but not in condition to operate is obviously to be distributed among the other components, but a record is kept of all time lost and all nonproductive labor so as to complete the performance record of both the machine and the operator. Continuous records have been kept of the various types of equipment in our service, and the rental basis has been adjusted each year to meet the fluctuating costs of labor and supplies. Such records prove to be educational, promote economy in purchase, operation, maintenance and repair, and are of value to the company from which equipment is purchased.

Without going into details, illustrations of three typical accounts will be of interest. Actual costs as percentages of the original investment and based on 1600 operating hr. per year were as shown in Tables 2 and 3

TABLE 2—COMPARATIVE RECORDS OF EQUIPMENT OPERATION

Equipment	Truck		Tractor		Steam Shovel	
Items	Percentage of Initial Cost	Actual Annual Cost	Percentage of Initial Cost	Actual Annual Cost	Percentage of Initial Cost	Actual Annual Cost
Average Annual Depreciation	19	$1,083	15	$900	11	$880
Equivalent Annual Interest	4	228	4	240	4	320
Storage and Incidentals	3	171	3	180	3	240
Insurance	1	57	1	60	1	80
Taxes	2	114	1	60	1	80
Total Fixed Charges	29	$1,653	24	$1,440	20	$1,600
Shop Repairs	8	$470	12	$720	11	$904
Field Repairs	7	400	10	600	6	467
Operating Cost	35	2,010	50	2,960	100	8,028
Maintenance	2	114	4	264	4	320
Total Operating Charges	52	$2,994	76	$4,544	121	$9,719
Total Annual Cost	81	$4,647	100	$5,984	141	$11,319

TABLE 3—COST PER MILE, PER HOUR OPERATED AND PER CUBIC YARD EXCAVATED

Items	Truck	Tractor	Steam Shovel
Fixed Cost:			
Per Mile Traveled[2]	$0.18	$0.80	$0.021
Per Hour Operated	1.03	0.90	1.000
Operating Cost:			
Per Mile Traveled[2]	0.33	2.43	0.126
Per Hour Operated	1.87	2.84	6.060
Total Cost:			
Per Mile Traveled[2]	0.51	3.23	0.147
Per Hour Operated	2.90	3.74	7.060

[2]For the steam shovel, this is per cubic yard excavated.

for a 5-ton dump-truck, a caterpillar tractor and a steam shovel. Being actual accounts of individual units these records are not intended as typical of the several classes of equipment, but are given only to illustrate the practical solution of the economic principles involved. The 5-ton dump-truck was purchased in 1920 and cost $5,700. Its estimated useful life is 4 years, and its total operation was about 3200 hr. when the truck was completely overhauled and retired, ready for the 1922 season. The caterpillar tractor was purchased in August 1919, and cost $6,000. Its estimated useful life is 5 years. It was used largely with elevating graders and grub plows. Its total travel was 4000 miles and the total time of operation 3400 hr. The tractor was put in complete repair for the 1922 season. The ¾-cu. yd. steam-shovel was purchased in August 1919 and cost $8,000. Its estimated useful life is 7 years. The total length of operation was 3921 hr. and the total amount of material handled was 190,700 cu. yd. This equipment was put in complete repair for the 1922 season.

The records of these particular units are given for three reasons: (*a*) the equipment built prior to 1919 was not up to the standard of the present day and comparisons would not be equitable; (*b*) each of these units has been operated continuously for 2 years, somewhat more than the estimated 1600 hr. per season, and has been completely overhauled and reequipped ready for the coming season's work so that all charges are included; (*c*) the truck represents the lowest ratio of operating cost to fixed charge, and the steam-shovel the greatest.

Operating-Cost-Fixed-Charge Ratio

I do not know how many are accustomed to view the cost of mechanical service from this angle but I wish to call attention to what seems to me the outstanding feature of these records, namely, the ratio of operating costs to fixed charges; 2 to 1 for the truck, 3 to 1 for the tractor and 6 to 1 for the shovel. The ratio of practically all other equipment comes between these extremes. Initial cost of equipment enters into the cost of service only in the fixed charges and, of these, depreciation is in every case more than 50 per cent. The percentage of depreciation varies inversely as the quality of the machine and as the initial cost. Machines of good design and high standard depreciate slowly. The higher the grade of the equipment is, the lower the fixed charge will be, as the decrease in depreciation will more than offset the small increase in the other components. Good design and construction decrease every item of operating cost; reduce shop and field repairs, lessen the amount of maintenance, tend to a more economical use of fuel and oil and result in better morale among the operating force. Good design and construction reduce lost time, increase output and decrease unit costs of work. I know of no better argument for the elimination of cheap or even doubtful materials and designs, regardless of the increase in the initial

cost, than the fact that, based on the annual cost of productive performance, a high initial cost increases only from 7 to 10 per cent of the total and reduces all other factors.

Records such as these carried through the life of a machine, with all operating costs itemized in detail, should and will become standard practice among all operators who expect to continue in and profit by the business. They will be good economy, for they will prove to the owner that

(1) Equipment is only as good as its operator, and cheap manpower is a fallacy
(2) Proper maintenance after operating hours decreases all other operating expenses, increases performance and justifies as much overtime as may be necessary
(3) With funds to cover the cost set aside from earnings, shop repairs in winter are well done without stinting and lost time becomes negligible
(4) First cost is no criterion; as fixed charges, aside from depreciation, which will reduce as standardization is perfected, are not excessive
(5) The guide to purchase is operating cost and performance made possible by continuous efficient service

Such records will show the designer and builder the success or failure of the product, what improvements are essential or desirable, the changes that will adapt the equipment to new conditions that may be encountered, the necessity of more educational propaganda, the desirability of a better inspection of materials and especially of the assembly, and the economic necessity of building the best that their ingenuity can devise for the operator who is in business to stay and buys and handles his equipment accordingly. Records that will permit the analysis of the cost of operation, maintenance and repair, as related to the fixed charges, are the means by which those who operate can assist the automotive engineer and the builder in the final standardization and perfection of types that will bring success in construction work.

THE DISCUSSION

A. H. BATES:—Are the labor rates you have used in computing the shop repairs higher than those that would be paid by a commercial house?

A. C. GODWARD:—I believe they are. We operate practically at the union scale. We pay time and one-half for overtime and the union scale in Minneapolis is higher than that paid by the ordinary tractor or commercial house. Operators received from 70 to 90 cents per hr. during 1920 and 1921. The operator of a steam-shovel gets about $1.25 per hr.

MR. BATES:—I understand that some operators were allowed 25 per cent of their actual time for repairing and keeping the machines in condition.

MR. GODWARD:—That is not so in our department. We pay our men by the hour and expect them to operate 8 hr. per day, the same as ordinary construction forces. After the day is over we expect every operator to see that his machine has the proper maintenance. It takes from 30 min. to 1 hr. He is paid for the time he puts in. On Sunday we insist that he drain the crankcase and clean the machine. For that time he is paid or will be paid straight time; in 1920 he was paid straight time and in 1921 time and one-half.

This maintenance charge, when many records of automotive equipment are analyzed, amounts to a considerable sum in dollars and cents, but the cost per mile or per cubic yard or per ton hauled is very small. Proper maintenance eliminates lost time almost entirely. Lost time is intangible; the lost time of a truck or shovel or piece of equipment is small and does not mean much. But if it disorganizes a crew of 100 men and 50 teams for 1 hr., it means money. It is something you cannot put down in black and white; it is nothing to which one can take oath; but by the time a job is finished the lost time is appreciable.

COKER F. CLARKSON:—How much of value has Mr. Godward been able to get from the recommendations of various organizations, including motor-truck companies, as to methods of maintaining cost-systems of motor trucks? Also, to what extent does he feel that the system that he has had in effect could be a basis for a generally acceptable system of keeping costs? Men who are engaged in research work in which the keeping of such costs is involved are very anxious to get on some sort of standard basis on which they can figure and which will, if possible, be generally accepted. It has been suggested that some such system be devised and promulgated, but this does not seem to be an easy thing to do.

MR. GODWARD:—We do not claim originality in our methods of keeping the cost of equipment. We consult with the distributors, get letters from the builders, and in many instances are personally acquainted with the designers. We find that their recommendations are not always the same; but we try to use the best of their several recommendations for our particular use. Being a comparatively small organization I doubt if our cost-system would be applicable to a fleet of from 30 to 50 trucks or tractors. We have a number of different types with diversified equipment and adapt our accounting system to particular cases.

MR. SCARRATT:—The hours of service that Mr. Godward figures these different pieces of equipment can stand is rather interesting. I believe he said they expect to use the caterpillar 1600 hr. in a year and estimate its useful life at 5 years. That is a total of 8000 hr. of service and usually it is pretty hard service. If this is compared with average automobile usage, taking even 25 m.p.h. as the normal driving speed, which is rather easy service, it is equivalent to 200,000 miles of use. You cannot get that much out of many cars.

MR. GODWARD:—The reason that we get 8000 hr. of work out of a caterpillar, or expect to, is that it is given proper maintenance. The man who drives that caterpillar does not abuse it, he sticks to it, he thinks something of it. Those who drive automobiles and many who drive trucks do not own the vehicles and do not care about costs. They get out at 20 deg. below zero fahr. and try to start with the starter when all that would be necessary is a little cranking. They do not watch the road. One could name many instances where money is spent that could be saved. In handling a caterpillar, wheeled machine or steam-shovel, each operator knows that the length of his job depends upon the cost of operation, and governs himself accordingly. One cannot emphasize too much the statement that maintenance means life, lower depreciation and service. The reason we get these things from high-priced machines is that we get high-priced men to run them, men who care for them.

CHAIRMAN W. G. CLARK:—An automobile driven at 25 m.p.h. for 200,000 miles is not comparable in the amount of work that the engine is called upon to do with a tractor working for 8000 hr. The average American automobile is overpowered. Four, 6, 8 and 12-cylinder engines, developing from 100 to 120 hp., are used in cars up to 4000 and 5000 lb., when all that is needed is 60 hp. This is a thing that many of us are prone to forget.

Those who are used to driving a car that loafs practically all the time do not realize this as strongly as they would were they to get into work where they would have to handle heavy-duty engines that work hard all the time until something happens. It takes more time for maintenance on a heavy-duty machine than on one that is loafing most of the time.

MR. GODWARD:—It is unfortunate that the man who governs is supposed to furnish the brains and set the example. The passenger car has lost its usefulness after 3 years at the most. Depreciation, instead of being 15 per cent, is 25 per cent. Fixed charges and operating costs run about 50-50. The same is true of trucks. The depreciation is higher than it should be. We hope with the assistance of the builder and the designer, and with a little cooperation from the operator, that the depreciation of trucks will not be 25 per cent.

L. C. HILL:—The public must take better care of its automobiles if it wants to get the results that are shown in Mr. Godward's figures. There is no reason we cannot eventually bring the passenger car to the point of efficiency that it should attain to be an economic factor and a really reliable and inexpensive means of transportation. The only reason it is an expensive means of transportation at times is that the owner insists on making it so.

MR. GODWARD:—In regard to the 8000-hr. life and some of the other lives that might seem too long, the machines are rented at a fixed rate per hour. The revenue from this rental is sufficient to give proper field-repairs in addition to maintenance and proper shop-repairs in winter. We do not consider that the machine is junk from the fact that it is in poor condition; we figure that as operating expense and have money for replacement. By proper replacement and repairs the life of the machine is lengthened, but this cannot be financed by hauling material at 10 cents per ton-mile in a truck. There must be the proper revenue to give the machine proper care.

W. J. MCVICKER:—What kind of fuel is used in the equipment?

MR. GODWARD:—Kerosene and distillates are used in some rollers, but in the higher-priced equipment, the equipment from which the best service is obtained, gasoline and the best grade of oil on the market are practically always used. In winter, low-grade gasoline is never used. High-grade gasoline cuts down condensation and assures proper lubrication. "Economy" in the use of fuel or oil is never tried. This shows immediately in the unit cost of work done.

O. W. YOUNG:—Of what do the operations consist in the case of caterpillar tractors? Was the work all a maximum drawbar load?

MR. GODWARD:—No. In the first 2000 hr. it was practically all elevating-grader work, largely old stumpage, about as much "grief" as can be given to a machine; some sand and some clay work. The winter work with snow-plows is small in hours and light in duty, ordinarily. There has been very little haulage of materials with this particular machine. It has been used in pulling stumps and trees; very heavy work. The elevating-grader work consisted of about 90,000 cu. yd. of material loaded by elevator, and varied from 400 to a maximum of 1000 cu. yd. per day. The heaviest duty on the tractor is in elevating-grader work where a turn, usually a one-way turn, has to be made every 600 ft.

MR. SCARRATT:—Does Mr. Godward mean to indicate that track maintenance is the chief item of expense of the track-laying tractor?

MR. GODWARD:—So far as I recall, the tracks and rollers are the principal items of depreciation.

MR. YOUNG:—How long do you operate the track-laying machines? When did you get the first machine?

MR. GODWARD:—I did not expect that caterpillar to be taken as representative of the type. I used it as an illustration of what our cost record brought out in the relation of the operating costs to the fixed charges. This particular caterpillar may be a good one or it may be a bad one. It was built in 1919, was operated continuously in 1920 and 1921 and is still going. It was cited to emphasize the small importance of the initial cost relatively to the actual cost.

SULPHUR IN BENZOL

PREJUDICE against the use of benzol as a motor fuel is being aroused by complaints that certain benzol-gasoline blends are proving very destructive to automobile engines. This is peculiarly unfortunate because benzol is the one fuel that has been found to be in all ways suitable for supplementing the gasoline supply.

The trouble is caused by sulphur introduced as an impurity, presumably in the benzol used for blending. An average crude benzol will contain as much as 1 per cent each of carbon bisulphide and thiophene, both of which form highly corrosive sulphurous acid when burned in a combustible hydrocarbon-air mixture. During the process of refining crude benzol, a large proportion of the carbon-bisulphide content is removed by rejecting the first runnings in the distillation process, and all but a trace of the thiophene is taken out by a sulphuric-acid wash. Refining practice has developed these two sulphur-removing operations to such a degree that the occurrence on the market of a motor-fuel benzol with a sulphur-content above the permissible limit is not the fault of the present state of the art of refining. The difficulty must be regarded rather as a preventable accident. Either the original supplier of the high-sulphur benzol was unskilled in modern refinery methods, or substitution, conscious or unconscious, has taken place. The low-boiling volatile benzol fraction that accumulates in the distillation process and is cheap because it contains the larger part of the undesirable carbon bisulphide, may have been substituted for refined benzol.

The dealer can easily safeguard himself by adopting the precaution of testing the benzol he puts into his blends. The simple copper-strip test, as used for sulphur in gasoline, is directly applicable to the detection of carbon bisulphide in benzol, and a benzol blend giving a positive indication by this test should be rejected as unfit for use in a blended motor-fuel. The extremely sensitive color-tests shown by thiophene could undoubtedly be adopted for detecting the presence of any undesirable amounts of thiophene sulphur in such motor fuel as may be offered for sale.

A situation analogous to the present instance existed in the early days of gasoline refining, and only a few years ago, when casinghead gasoline was being introduced, gasoline containing sulphur was on the market. Under present conditions, however, the consumer is well protected against the presence of sulphur in the gasoline he buys. There is no technical reason why the same reputation for reliability should not apply to the benzol supply.

The Comparative Merits of Benzol and Gasoline as Engine Fuels

By W. O. Hinckley[1]

Mid-West Section Paper *Illustrated with* Chart

THE process of manufacturing benzol is described briefly and a specification for motor benzol is stated. Comparison is made with a specification for gasoline and distillation curves are shown. Comparisons are made between motor benzol and gasoline in regard to end-point, heat value and vapor-tension, together with miscellaneous data on pure benzol, motor benzol and gasoline.

A description of comparative engine tests made with motor benzol and with gasoline as fuel is included and the observed results are enumerated. The author states that the data relating to the fleet of vehicles he mentions show about 10 per cent in favor of motor benzol over the results obtained when operating on gasoline.

THE respective merits of gasoline and benzol as internal-combustion-engine fuels have caused many a discussion in the automotive world and, for this reason, I will give a short history of benzol that is taken from actual occurrences in Chicago. When benzol in its crude state was first introduced there, the large oil companies tried hard to annihilate it, because it is the only fuel that has the market name of being a competitor of gasoline. Due to this fact the oil companies came out with various derogatory phrases that, at the time, were justified in some degree and in some instances are logical to-day. A few years ago several companies were making benzol for the internal-combustion engine and were successful until the cold weather set in; then the benzol froze in the gasoline tanks on the street. Many incidents of this kind and troubles with sulphur and acids left a doubt in the public mind about the value of benzol as an engine fuel. Experiments continued and, due to research, benzol was introduced as a stable fuel on the market. Were it not for the limited supply, benzol would, in my estimation, replace gasoline as a motor fuel within a short time.

The question is often asked: What is benzol and where does it come from? It is derived from coal carbonized in a by-product or recovery oven. There are four principal resultant products; ammonia, gas, tar and coke. While small quantities of benzol are recoverable from the light oil of coal tar, almost all benzol recovered is from an oil obtained by scrubbing coke-oven gas.

Briefly, this coke-oven light-oil is obtained by passing oven-gas through "scrubbers" against a counter current of heavy petroleum. The light oil removed in this way is separated from the scrubbing oil by distillation, and the quantity of oil obtained varies with the nature of the coal coked, ranging from 1½ to 4 gal. per ton of coal. The light oil is then refined by distillation in fractionating column stills, sulphuric-acid washing and subsequent neutralization with caustic soda, thus producing certain water-white distillates which, when properly refined, respectively create pure benzol, toluol and xylol.

[1] Superintendent of transportation, Peoples Gas Light & Coke Co., Chicago.

TABLE 1—SPECIFICATION FOR WATER-WHITE BENZOL

	Temperature	
	Deg. Fahr.	Deg. Cent.
Distillation:		
First Drop	175	79.4
60 Per Cent	212	100.0
90 Per Cent	250	121.0
Dry	275	135.0

[2] Residue, none. It must be neutral, containing no solids and practically no foreign bodies except slight quantities of sulphur present as CS_2, or thiophenes to total approximately 0.25 per cent. Specific gravity at 15.5 deg. cent. (60 deg. fahr.) 0.878 or 29 deg. Baumé.

Motor benzol therefore is a distillate conforming approximately to the specification given in Table 1.

Motor benzol will pass the doctor test and the corrosion and gumming test for gasoline. The doctor test is supposed to show sulphur, and the corrosion and gumming test to show residues. Comparative distillation curves are shown in Fig. 1.

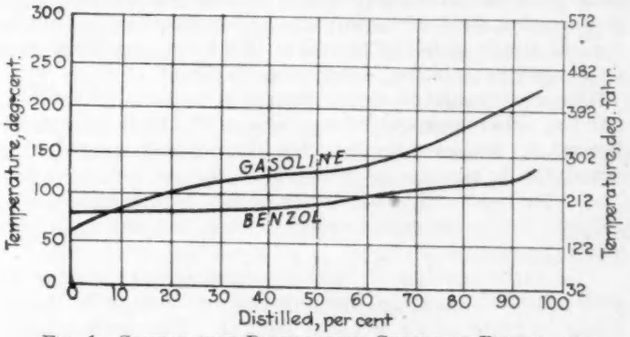

Fig. 1—Comparative Distillation Curves of Benzol and Gasoline

Comparison with Gasoline Specifications

A comparison of motor benzol that meets the specification in Table 1 with commercial gasolines produced to-day is interesting. The products of refiners vary over a wide range. A few years ago the standard end-point for gasoline, the temperature at which it is completely vaporized, was from 330 to 350 deg. fahr.; to-day it varies from 400 to 500 deg. fahr. and in some instances it is as high as 600 deg. fahr. A distillation test of a high-grade sample of motor gasoline is given in Table 2, this

TABLE 2 — HIGH-GRADE MOTOR-GASOLINE DISTILLATION-TEST[3]

	Temperature	
	Deg. Fahr.	Deg. Cent.
Distillation:		
First Drop	135	57
20 Per Cent	212	100
60 Per Cent	288	142
90 Per Cent	387	197
93½ Per Cent Dry	417	214

[3] Residue 0.2 per cent. Specific gravity at 15.5 deg. cent. (60 deg. fahr.) 0.732 or 62 deg. Baumé.

test having been made recently. However, we are not getting very much of this grade of fuel in Chicago.

While the initial point for the gasoline sample in Table 2 was 135 deg. fahr. as compared with 175 deg. fahr. for the motor benzol in Table 1, the gasoline shows only 20 per cent distilled off at 212 deg. fahr., the boiling point of water; whereas the motor benzol distills about 60 per cent at 212 deg. fahr. The end-point of the sample of gasoline was 417 deg. fahr. as compared with 275 deg. fahr. for the motor benzol. There was a residue of 0.2 per cent with gasoline, but the motor benzol shows no residue on distillation.

What the End-Point Indicates

The so-called end-point referred to is a very important indication of the efficiency of motor fuel. A high end-point indicates the presence of non-volatile constituents such as kerosene, which, if present in too great an amount, would reduce the efficiency of the motor fuel. Various methods are used in demonstrating this. A simple one is to compare the time of evaporation or volatilization of a fuel having a high end-point with one of a low end-point. This was done with the sample of gasoline referred to in comparison with a typical motor-benzol sample. This test was made by an arbitrary method; an equal amount, 5 cc., of each material was permitted to evaporate from an alberene stone dish, approximately of 4-in. internal diameter, under similar conditions. The evaporation time of benzol was about 26 min. and of the typical motor gasoline 145 min. High-test gasoline, such as is used in aviation, evaporates in about 11 min.

The heat value of motor benzol is about 18,700 B.t.u. per lb.; whereas gasoline has about 17,460 B.t.u. per lb. Benzol is considerably heavier than gasoline, weighing about 7.3 lb. per gal. as against 6.5 lb. per gal. for gasoline. The heat value for motor benzol is therefore about 137,000 B.t.u. per gal. compared with 113,500 B.t.u. per gal. for gasoline.

The vapor-tension of motor benzol is high compared with that of gasoline and, therefore, benzol is quick-firing in spite of its greater weight. The boiling-point of a liquid is an indication of its vapor-tension; for, as a general rule, as the boiling-point goes up, the vapor-tension comes down. Motor benzol has an average boiling-point of about 190 to 194 deg. fahr.; gasoline will run about 256 deg. fahr. or better.

Table 3 gives comparative data submitted by C. S. Heath, a chemist who has grown up with the development of benzol in this section of the Country, and is largely responsible for having solved the problem of preventing benzol from freezing.

During a recent test on a four-cylinder engine rated at 35 hp., we were successful in developing 36 hp. with motor benzol against 32¼ hp. with gasoline at 1900 r.p.m. A run of 6 hr. at approximately 1064 r.p.m. was made with both fuels. The following results were determined with the throttle wide-open. Before starting, the engine was dismantled and various parts were cleaned; new piston-rings were installed and the valves were reground.

During the run with straight gasoline the engine developed 24 b.hp. and consumed 19.1 gal. of fuel; or 2.94 gal. per hr. This is at the rate of 0.122 gal. per hp-hr. After this run was completed the engine was dismantled and what carbon had adhered to the top of the pistons was scraped off and weighed. On account of the shortness of the run there was only about 1.8 grams of carbon, some of which was due to the pressure of oil in the cylinder, caused, no doubt, by the installation of new piston-rings. The porcelain of the spark-plugs was slightly carbonized. The valves and valve-caps had a light carbon soot that could be scraped off readily.

For the run with motor benzol, we adopted the same procedure as when gasoline was used, reassembled the engine and put fresh oil into the crankcase. Then we adjusted the carbureter to a leaner mixture and retarded the ignition slightly. On this test the engine developed 26 b.hp. and consumed 13 gal. of fuel. The increase in power over that of the gasoline run was noticeable. During this operation the consumption was 2.89 gal. per hr. or 0.109 gal. per b.hp-hr. This shows about 10.7-per cent greater efficiency than the gasoline test. The engine ran more evenly throughout this portion of the test than in the previous run on gasoline, and did not appear to labor as much. An examination of the engine showed less carbon on the pistons; in fact, except for the small amount of carbon around the edges of two of the cylinders, there was not enough carbon to weigh. The centers of the pistons had practically no carbon, and the valves, valve-caps and spark-plugs were practically free of carbon. What little carbon we succeeded in locating was easily removed, due to the fact that it was not of the hard texture found when using gasoline as fuel. We also noted that the average temperature of the cooling water was not so high as when gasoline was used as fuel. With benzol we obtained a better running engine than when using gasoline.

In conclusion, I wish to state that the real test of any fuel is the result obtained in actual service. However, we have data showing that we are about 10 per cent better off in operating our fleet on motor benzol than we were when gasoline was used.

TABLE 3—COMPARATIVE DATA ON BENZOL AND GASOLINE

	Pure Benzol	Motor Benzol	Gasoline
Approximate Flame-Temperature, deg. fahr.			
With Air	3,650	....	3,500
With Oxygen	7,180	....	6,750
Heating Value, B.t.u. per gal.	137,000		113,500
Air Required for Combustion of 1 cu. ft. of Vapor, cu. ft.	36	39	45
Air Vaporized per Gallon, cu. ft.	39	35	25

The Discussion

H. W. Haines:—Is there any corrosion after some months due to the small sulphur-content? That is the principal point in the whole benzol situation.

W. O. Hinckley:—It is found with some grades of benzol but, when benzol is properly distilled, I think that the greater part of that difficulty is obviated. Other companies are not getting any of our benzol to-day because it is a question of our getting enough of it for our own use, due to the fact that we obtain only 4 gal. of benzol per 1000 cu. ft. of gas. One company in Chicago built up a reputation through the use of this fuel, because it was as nearly perfect a product as anything they found in research. One or two of the companies in Chicago are having a little trouble with corrosion.

Mr. Haines:—Do you contend that if benzol is properly refined the sulphur-content can be neglected?

Mr. Hinckley:—Absolutely. I will not say that I have no trouble. It does not happen often, but I have to caution our powerplant occasionally.

C. B. Page:—Mr. Hinckley has indicated that not very much benzol is available. Does this mean that benzol

will not cut much figure in reducing the price of gasoline?

MR. HINCKLEY:—Yes. Benzol sells to-day for 1½ to 2 cents more per gal. than gasoline, and it will continue to do so.

MR. PAGE:—Is there any prospect that the supply of benzol will become so great as to add materially to the supply of volatile fuels and thus assist in keeping down the price of gasoline?

MR. HINCKLEY:—No. The oil companies thought it would at one time but it will never come to that point unless gas is used universally as a fuel. That possibly would enable the gas companies to get enough production, but it would mean that residences would be heated by gas, steam boilers and office buildings would use it and, instead of getting fuel from various points, it would be taken from one center, practically speaking. The gas company hopes to be in a position some day to get the price of gas down where you will be heating your homes and business buildings with gas.

MR. PAGE:—My recollection is that, for general heating purposes, it was not contemplated to enrich that gas, but simply to pipe a gas having no illuminating qualities and a low heat-value through the streets.

MR. HINCKLEY:—The public-utility commission specifies a certain number of heat units for gas. I think the commission will never allow gas quality to get down to as low a point as 125 B.t.u. per cu ft. of gas.

G. W. CRAVENS:—What is the relationship between the benzol Mr. Hinckley referred to and benzoline, which has been marketed as a commercial fuel for some time?

MR. HINCKLEY:—Benzoline is a motor benzol. Just what the mixture is, I am not in a position to say, but it is pure benzol derived from the steel coke-ovens, or the recovery by-product ovens of coke companies.

MR. CRAVENS:—In the winter of 1920-1921, when the question of corrosion was raised, I tried to find out about it. We ran about 3000 miles on benzoline and found less carbon in the engine and no corrosion whatever. We had three Ford cars running as light trucks and service cars. We had been told that the use of benzoline would ruin the engine.

Mr. Hinckley said that when operating on benzol the engine ran better than on gasoline. Did he mean by that less detonation?

MR. HINCKLEY: — I meant less vibration; in other words, the exertion did not seem to be there. We got better explosions on benzol.

MR. CRAVENS:—Do you mean you got less detonation and really better combustion?

MR. HINCKLEY: — Yes, better combustion all around. We are continually dismantling engines and they show very little carbon deposit; even on oil pumpers, the residue is nothing like it is when operating on gasoline. I have seen the carbon deposit on gasoline-operated engines loosened with a chisel but I never see one of my men do anything more than to use a screw-driver and push the carbon deposit off of the cylindler. If the engine is not an oil pumper, a rag will get all the carbon out. The only carbon that can be seen has the color of lampblack, with a little reddish hue to it.

CHAIRMAN B. S. PFEIFFER:—You spoke of a 50-50 benzol-gasoline mixture.

MR. HINCKLEY: — That is approximate and varies somewhat according to the weather. In cold weather very often 60 per cent gasoline and 40 per cent benzol is used; in hot weather, the proportions may be reversed, but those two points will cover any mixture that is used in the average motor-benzol. In hot weather we use as much benzol as we dare until we hit what we term the heating-point; that is, the danger point of heating up the engine; and we mix the fuel accordingly. With pure benzol, I can tie up almost any engine because of expansion, right on the street, if the weather is at all warm and the engine uses an ordinary water-cooling radiator.

CHAIRMAN PFEIFFER:—Have you ever made any experiments on increasing the amount of radiation?

MR. HINCKLEY:—No; but, judging from what we have done on Ford and Pierce-Arrow cars, nearly three times as much radiation is needed as the cars have at present, and very nearly that much extra water to keep the engine cool.

JOHN W. STACK:—With regard to detonation, there are some peculiar and I might say not thoroughly understood properties about those hydrocarbons that are different from gasoline. Possibly they operate differently in an engine. I have never tried benzol.

CHAIRMAN PFEIFFER:—I think that Mr. Stack's point about the differences between these hydrocarbons and gasoline is the whole thing.

MR. HINCKLEY:—I have known men who have changed from gasoline to benzol when they knew they were having trouble with carbon. When they put benzol in their engines they got just enough heat to cause that carbon to preignite the mixture and they had difficulty in reaching the nearest service-station. It is not unusual to hear that benzol will cause knocking and that gasoline will stop the knock, and you will hear the same thing about gasoline. The average benzol will eat the carbon out of any cylinder in 90 days or more. It will eat out all of that hard carbon unless the engine is an oil pumper, in which case the oil is causing the carbon.

A MEMBER:—In regard to whether benzol is a fast or a slow-burning fuel, it seems to me that it must be slow-burning because it heats the radiator more and carries the flame longer, more heat going into the water-jackets.

MR. HINCKLEY:—There is more heat to it, but it has a very short flame.

A MEMBER:—I cannot understand how it heats the radiator more.

MR. HINCKLEY:—I can explain that for pure benzol. If it has a short flame it has a terrific heat at the explosion point when properly mixed with air; whereas gasoline, which is less volatile, does not give so much heat.

A MEMBER:—But when you make a mixture that burns slowly and carries the flame down for a long time it always heats the radiator. That is the same condition.

MR. HINCKLEY:—If you carry that flame down in the open it might, but when confined in a cylinder it is so instantaneous that you do not get much effect from that heat in the lower part of the cylinder. If you did, you would have to give more clearance on the piston, right straight down. In other words, you would be getting the same temperature at the bottom of the cylinder because the flame is spent by the time the piston gets down there, and it is coming back so quickly that that space is not open to the firing point the same as the top of the cylinder.

M. J. HENDRY:—Thomas Midgley, Jr. deduced the fact that benzol is a slower-burning fuel, although it is volatile. Argument that the hydrocarbons in gasoline burn faster, offsets the argument about the carbon. If the engine of a car is loaded with carbon and benzol is put in there, that knock will be eliminated altogether, even though the carbon is in there.

MR. HINCKLEY:—That occurs sometimes.

MR. HENDRY:—In a large percentage of cases benzol will gradually take the carbon out of the cylinders, and

that offsets the other argument about carbon causing the knock. The carbon does not cause the knock; it is caused by the fuel. The hydrocarbons burn more slowly and that eliminates the knock, but they burn faster in gasoline and cause the same kind of detonation as with dynamite.

MR. HINCKLEY:—I disagree on that point. In a long flame the heat temperatures remain longer in the cylinder due to the fact that the cylinder has no chance to clean out and cool. In a short flame, the flame does not have the force behind it and the piston has a chance to clear the cylinder. The more quickly the flame clears from the cylinder, the less heat it will maintain. I defy anybody to show that gasoline has a shorter flame than benzol, irrespective of what make it is. Benzol is a quick-firing fuel.

A MEMBER:—The indicator-card should show that.

MR. HINCKLEY:—It does. Benzol shows a very short flash, also motor benzol mixed with gasoline.

L. E. GOIT:—An intensely luminous flame can be produced under some conditions that carries a very great percentage of heat which can be lost instantly in the jacket without delivering any sensible heat to the air or the other gases in the mixture; whereas a blue flame, or something approaching that, although there is seldom a real blue flame in the cylinder, has a tendency to turn the heat into sensible heat, and only what can be lost by contact with the cylinder is rejected to the jacket. I do not know how benzol acts in a cylinder or whether it has a blue flame. but there would be a chance for an explanation in that.

MR. HINCKLEY:—The benzol flame is almost blue.

MR. GOIT:—That would be against my explanation of the enormous heat-loss that pure benzol or perhaps a mixture of benzol and gasoline gives, because of having a luminous flame. C. A. French advanced a theory about some of the causes of detonation,[4] based on the relative sizes of molecules, the possibility of burning a molecule of the fuel at one flash or having it so big that the air could not possibly get into it to burn it at one stage, but there may be various waves of pressure and perhaps several detonations in the burning of a fuel that is as heavy as kerosene, for instance. Benzol is a comparatively light fuel. According to that theory, it would be possible to burn it at one flash without having the oxygen delayed in getting into a lower layer of the atoms in the molecule.

MR. HINCKLEY:—That is my argument; the longer the flame continues, the more heat you will get out of it. On the other hand, with almost any engine, retarding the ignition a little and making the fuel mixture leaner, will give from 18 to 24 per cent more brake horsepower than you can get out of the engine when using gasoline, so long as the engine lasts. With a proper amount of cooling water, that can be done continuously.

MR. HAINES:—Has the matter of corrosion due to benzol been investigated at average combustion-temperatures?

MR. HINCKLEY:—No. We did not have the necessary instruments. However, several benzol users who have experimented in that regard say that motor benzol does not create much more temperature at the explosion point than is the case with gasoline.

CHAIRMAN PFEIFFER:—It is difficult to put forward any theory as to why so-called motor-benzol acts as it does, because you have the effect of the benzol on the other half of the mixture.

MR. HINCKLEY:—The condition is not due to benzol alone; you are putting toluol in there and that helps a whole lot.

CHAIRMAN PFEIFFER:—It is as bad as trying to prove a theory in connection with so-called gasoline. You have a number of different fuels and each one acts on the other; it is difficult to determine the resultant action.

MR. HINCKLEY:—It is difficult to buy gasoline from any two stations in Chicago that will show the same analysis. There are various causes for discussion about benzol as a fuel. Few people are familiar enough with it even to-day to say whether benzol or gasoline is the better fuel. It is only a personal opinion as a general rule.

HENRY FARRINGTON:—Have you any comparative data on the mileage per gallon with Ford cars, using gasoline, this benzol mixture and the pure benzol?

MR. HINCKLEY:—We cannot give comparative costs on the same make of car. The cost on an 800-lb. Ford truck is about 10.5 cents per mile, including depreciation, insurance, overhead, tire mileage and everything else. The Ford 1-ton truck operates on an average of about 12.5 cents per mile.

MR. CRAVENS:—If you consider that commercial Benzoline is similar to your motor-benzol, I will give a comparison on two Ford cars each having a standard passenger-car chassis. One had a special body that made it weigh about the same as a Ford sedan and was used as a passenger car. The other had a light body and was used as a truck. They averaged about 12 miles per gal., in winter, on gasoline such as we bought in Indiana in 1921. This was on short hauls and through more or less snow. On Benzoline that cost 2 cents more per gal., we averaged between 18 and 19 miles per gal.

Referring to the injection of water, or to using steam in the intake-manifold, we made some tests on a Dodge touring-car with what was known as a steam carbureter. This is a device that takes water from the radiator and pumps it through a valve into the intake-manifold. When running along at 1200 r.p.m. without the steam injection, we found that by merely turning a valve and injecting a little vapor the engine speed immediately increased to 1800 r.p.m.

MR. HINCKLEY:—You would find the same effect if air were injected into the manifold. You can take air as it comes out from under the hood, cut an opening in the manifold and place a spring so that the vacuum will not open the spring until you reach a speed of 15 m.p.h. When the spring opens, the speed will jump to 20 m.p.h. without moving either the spark or the throttle. My objection is that the faster those engines are made to rotate, the faster the truck drivers will drive them, and vibration has a serious effect, especially on a 1-ton Ford truck. However, this does not increase the mileage, and we had no success with it.

MR. CRAVENS:—One injector device consists of a plunger with a dash-pot control to prevent it from operating too quickly. It leads into the intake-manifold for the purpose of letting air in, but it is controlled entirely by the throttle; that is, it will not come into action until the throttle has been opened to a certain point. We have found on testing Ford, Dodge, Nash and several other makes of car, that we increase the mileage from 30 to 70 per cent by the use of the valve, depending upon the make of the car.

[4] See THE JOURNAL, September, 1921, p. 182.

Some Aspects of Air-Cooled Cylinder Design and Development

By S. D. HERON[1] DAYTON SECTION PAPER

ON account of the exceptionally interesting character of this paper a departure was made from the usual practice of printing Section papers and the discussion following their presentation in the same issue of THE JOURNAL. To enable the members who were unable to be present at the March meeting of the Dayton Section to have the benefit of Mr. Heron's experience the paper was published in the April issue of THE JOURNAL. In accordance with the customary procedure the stenographic report of the discussion was sent to the various speakers for any corrections that they wished to make before the report was published and also to the author for him to reply. While Mr. Heron has replied to the discussion at the meeting, it is his expectation to incorporate the results of some later work in the discussion when it is printed in the TRANSACTIONS for the first half of the present year.

For the convenience of the members an abstract of the paper precedes the discussion.

ABSTRACT

THE paper reviews some of the salient points arising in the design and development of the modern high-output air-cooled cylinder. It is based to a very large extent upon the work of Dr. A. H. Gibson at the Royal Aircraft Establishment, which in turn was principally a development of the pioneer efforts of Renault, supplemented by some post-war work of the author for British companies and tests made by the engineering division of the Air Service. While the paper may, therefore, lack somewhat in originality, many of the results presented, it is stated, have not been published previously. The problems of an aircraft cylinder of approximately 40 b. hp. are dealt with primarily, but some aspects of automobile-engine cylinder design are considered.

The first point treated is the heat to be dissipated, this being followed by a consideration of how to secure an even temperature-distribution in the various parts of the cylinder. Cooling by a direct air-blast and by conduction is discussed, the importance of removing the heat from the cylinder at the point where it is given to the head, the ports and the barrel being particularly emphasized. The effects of mixture-strength and cooling air-supply upon the cylinder temperature are commented on, the text being supplemented by a number of tables. Methods of finning different forms of cylinder, the cooling surface required; the effect of the compression-ratio on the output, fuel-consumption and wall-temperature; cylinder materials; types of cylinder, with a summary of the advantages and disadvantages of the different forms of construction, valve-seat inserts in aluminum cylinder-heads; exhaust-valve cooling; and valve-gears, all receive attention.

The conclusions reached are that (*a*) successful air-cooling is not limited to 50 b. hp. per cylinder, (*b*) fragility of the fins is a disadvantage of air-cooling and (*c*) the compromises necessary in the design of air-cooled cylinders have been made at the expense of the cooling efficiency.

The effect of the position of the spark-plugs on the power output and the fuel-consumption is discussed in an appendix and the use of two spark-plugs located on a common horizontal axis that passes through the vertical axis of the combustion-chamber in such a position that neither plug can project a flame-wave against the exhaust-valves is commended. The influence of gas velocity through the valves on the performance of an air-cooled engine is the subject of a second appendix. In this, as throughout the paper proper, numerous illustrations and tabulations of test results supplement the text.

THE DISCUSSION

CHARLES L. LAWRANCE:—Having had some experience in preparing a paper of this sort, and seeing the tremendous detail and difficulties involved, I am awed at Mr. Heron's work on this paper. As it follows closely along the line of my own work, I cannot think of any criticism to make although in one or two instances I have had experience that differs somewhat from his.

One of the few things that I might mention is the question of a cylinder constructed with a shrunk-in liner, which is the type we now use. With this type of cylinder I find, contrary to European experience, that the performance after a number of hours of running, which is supposed to produce a high fuel-consumption, was, if anything, better after 70 hr. of running than at the start; probably due to decreased friction.

In some ways the cylinder with a shrunk-in liner has some advantages; it is easier to produce. In sizes such as we have here, it is very probable that it would be unsatisfactory, although I have had no experience with them and speak only from experience with small cylinders up to 30 hp.

J. H. HUNT:—One thing that impresses me on reading this paper is that it would have been a mighty good thing for the development of the automobile industry if every engineer had been compelled to work first with an air-cooled engine. There is considerable important information implied in the curves of Fig. 5, showing the variation of the head temperature with the quality of the mixture. The facts implied are just as true of the water-cooled as of the air-cooled engine, but the average engineer working on the former type has failed to get the point. So often he has set up his engine with his cooling system connected to the city water-supply and turned on enough water to maintain the temperature at the point that he finds gives the best performance without making sufficiently careful measurements of the distribution of the rejected heat, that he has failed to learn many things that he would have been compelled to learn if he had worked with air-cooled engines. I hope that those having the information as to engine conditions indicated in the curves of Fig. 5 will soon be in a position to give us their analysis. Mr. Heron states in his paper that in his opinion cast iron is the best all-around material for air-

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cooled cylinders for other than aviation purposes. I have not read Mr. Heron's paper as carefully as it deserves, but have not seen many data in support of this particular statement. If Mr. Heron can discuss this point more fully it would be greatly appreciated, as more data on this question are very desirable.

H. M. CRANE:—I feel that this paper is a challenge to every man who is designing a water-cooled engine; it shows him that he is many laps behind. The designer of an air-cooled engine has had to make an effort to make it run. This paper is of value to the designer of water-cooled cylinders for the reason that it contains a very thorough study of where the heat appears in the cylinder and where to get rid of it, which is as essential in water-cooling as it is in air-cooling. The cylinder developed in the past has been designed to act as we wanted it to; then we put a water-cooled jacket around it and hoped that the water would find the weak spot. I have had cylinders in the past that would pump 2 gal. of water out of the radiator when the engine was practically stone cold. It was just a case of the water refusing to do what I expected of it, which was natural because it was not treated right.

I am not ready to believe that the water-cooled engine is dead for aircraft work. One of the advantages of water-cooled engines is that we can give more consideration to the shape and arrangement of the cylinders and the general layout of the engine than is possible with the air-cooled types. Fundamentally the condition is the same in both. Heat is delivered to the cylinder and must be disposed of. In the case of water-cooled engines, we lead it away and then it is dissipated in the air; in the case of the air-cooled engine, it is dissipated to the air as close to the place where it originates as possible.

Another feature of air-cooled engines in aviation that is far from settled as yet is whether cooling directly in the slipstream is justifiable. I feel that it will not be on high-speed airplanes and, after looking over Mr. Heron's work, I am fairly well satisfied that it is not necessary to do it in the slipstream. In types of engine other than the radial, air-cooling may prove to be even more satisfactory. I certainly hope so because I think that the radial engine, due to its form and larger size, is a very unfortunate form for airplane use, as it is hard to push through the air and cuts off the pilot's view in a very important direction.

CAPT. LORENZO L. SNOW:—The air-cooled engine is somewhat out of my field, but I am in accord with Mr. Crane's statement that in the present status of development the water-cooled engine is much easier for us to handle and we gravitate to it on that account. The development of air-cooled engines is before us, particularly where cylinders of the larger sizes are involved, and this should be a challenge for us to keep at it. I suggest that a little more emphasis be placed on the actual ground covered and the success achieved to date with large air-cooled cylinders. We know that with small cylinders we are getting along very well; with larger ones the results are not so generally understood. The latter are being developed and I suggest that Mr. Heron tell us more of how they are actually performing in the air, and what his predictions are as to their filling military requirements.

V. E. CLARK:—The matter of air-resistance of exposed air-cooled cylinders as adversely affecting speed and general performance is important, and designers of radial air-cooled engines must go far to reduce this before the same speed is possible with air-cooled as with water-cooled engines. Suppose for example we have an airplane with which we are trying to get a speed of 150 m.p.h. at a great altitude. The specifications include the requirement that the engine cool while running on the ground without excessive fuel-consumption. It is assumed that the engine is mounted in the nose of the airplane in such a manner that the form of the nose of the fuselage is not susceptible of change. Now the air-speed past the cylinders at 150 m.p.h. is more than three times that of the propeller slipstream while standing on the ground. Therefore, the resistance at high speed is more than nine times as great. Hence, the horsepower actually consumed in cooling the engine at high speed is more than nine times that actually necessary. As against this, refinements in radiator design and installation for water-cooled engines, such as retractable radiators, go far to obviate this condition. The comparison is even worse at great altitude, because then the air is much colder and it may be that, in such conditions, as much as 15 times the horsepower is used in cooling radial air-cooled cylinders as is actually necessary. In an airplane otherwise well cleaned-up and streamlined, the percentage of available horsepower that is lost in this manner may become very great.

E. H. DIX, JR.:—Mr. Heron's paper gives us a clue to the reason for his success with air-cooled engines; namely, his wide and very practical acquaintance with all phases of his subject. Of course I appreciate his consideration of the foundry more than anything else. Most of the early failures of air-cooled cylinders, either by blowing off the head or the opening up of cracks, could be traced back to stresses set up during casting. The foundry was called upon to carry too much of the designer's burden.

Our first experience with air-cooled cylinder-heads came in connection with a cast-on head with cast-in valve-seats and spark-plug bushings. It was a four-valve flat-head design and, to make matters worse, we had an all-wood pattern that had to be sent back to the pattern-shop to have the fins glued up every time we put it in the sand. So when Mr. Heron brought us the first of his patterns, the three-port Type I design with very slick aluminum fins, we had reason to know that he had not been as mean as he might have been. Accordingly we told him that there was nothing to it and got busy. We found we had to experiment with sand mixtures to obtain a good slick surface on the fins without getting too dense a mold and so cause blows. We lost two castings before we determined the lowest pouring-temperature at which we could completely run the fins and a third when the mold washed where it was not properly secured, but then the next two were satisfactory and we have every reason to believe that we could make a very fair production record on this particular cylinder.

The next cylinder that we worked on was the two-port Type J design, which caused some trouble in the molding due to one place that was hard to lift, but the first two castings that we poured were satisfactory. The four-port Type H design caused us more trouble in the molding than either of the other two, but again we saved the first two cylinders that we poured.

I have mentioned our experience with the casting of these cylinders because undoubtedly the foundry problem is one of the most difficult to be met by the designer of the air-cooled cylinder. It is chiefly a molding difficulty; for, once the mechanical difficulties of preparing the mold are overcome, the metal problems are slight. We have had little occasion to worry over shrinks, draws, porous metal or cracks in the three designs mentioned.

The contrast between molding with the first all-wood

pattern and the later metal-fin patterns gives an indication of the improvement in ease of molding that may be made possible by refinements in patterns and perhaps the use of jolt ramming-machines. The foundry must be educated to take its proper share of the burden in the development of air-cooled cylinders. It is not sufficient to design a cylinder amenable to good molding, but we must go farther and develop the method of molding so that we *know* it is a good production job.

C. F. TAYLOR:—The water-cooled engine designers might have learned much if they had started in on air-cooling. This is particularly well illustrated by some of the exhaust-valve temperatures observed in the laboratory of the Engineering Division. On one of Mr. Heron's cylinders running at present, the exhaust-valve appears to run much cooler than any exhaust-valve in a water-cooled cylinder of a similar size. There are many theories as to the cause of this, but none has been proved definitely. Given a valve of the same size and cylinders of approximately the same size, the air-cooled exhaust-valve will run very much darker in color than the water-cooled exhaust-valve.

With regard to the necessity of air-cooling under certain conditions, we look forward to aviation that wi l encircle the globe, and we think possibly that one of the great fields for aviation will be over territory where there are no other quick forms of transportation. I refer to such regions as Alaska and others having very cold climates where transportation facilities are needed but at present are not available, and where the airplane may become one of the most important methods of travel. Temperatures in Alaska run as low as 40 deg. below zero fahr. in winter. Automobile drivers can understand what that means for the water-coo'ed engine. I do not believe that there is any satisfactory anti-freezing solution that could be used at 40 deg. below zero. This means that if aviation spreads out into such territory as that, we must use air-cooling.

The foregoing remarks apply also to very hot climates that make water-cooling very difficult, because there is a high limit of the temperature at which the water-cooled engine can be run. It is practicable to run air-cooled engines at cylinder temperatures considerably higher than is possible with water-cooled engines. In some of the Mesopotamian campaigns it was said that the desert was strewn with the remains of water-cooled engines in which the radiation surface had not proved large enough to withstand the heat. I believe I am right in saying that the British used air-cooled engines almost exclusively in this region during the war.

LIEUT. ERIK NELSON:—Shortly after my trip to Alaska, I visited my own country, Sweden, where they were doing considerable flying. Only air-cooled engines were used there. They were carrying mail every day 50 or 60 miles farther north than we were. In Alaska we got as far as Nome, 60 miles south of the Arctic Circle. They were flying that winter in Sweden 30 miles north of the Arctic Circle, and only air-cooled engines could be used. They were of British design. The temperatures run from 35 to 50 deg. below zero cent. (31 to 58 deg. below zero fahr.). The people are anxious to get mail service in Alaska and, as the weather there in winter is very cold, satisfactory air-cooled engines are absolutely necessary. Heated hangars and numerous other auxiliaries are necessary to handle the engines satisfactorily.

GLENN D. ANGLE:—Will Mr. Heron explain why aluminum construction is preferable to the use of metals showing high conductivity?

CHAIRMAN G. E. A. HALLETT:—While flying at Petrograd, Russia, in the fall of 1912, the cold weather did not bother the engine but it did cripple our airplane. We used a Curtiss pusher-type hydroplane and, in running on the water preparing to take-off, the spray froze on the tail and jammed our controls and we found ourselves on the water with no means of controlling the airplane. The weather was not cold enough to give us trouble with the engine.

LIEUT-COM. KARL F. SMITH:—A rather paradoxical fact has been developed in connection with the cooling of aeronautic engines which is that by coating the cylinders with certain enamels that are excellent heat-insulators, the effect is to increase rather than diminish the radiation. The reason for this is not fully understood, but much research on this particular phase has been done by Doctor Gibson and his co-workers in England. The failure of certain Hispano-Suiza engines in use was attributed by the manufacturers to the fact that the enameling was imperfect or broken off. This enameling seems to work equally well with water-cooled cylinders. The enamels employed are usually those having a Kauri Copal base, the mastics being less efficient. Black seems to be the best color to use, irrespective of theoretical considerations. The increased efficiency of heat dissipation in using cast-iron cylinders is about 2 per cent but varies with the cylinder material and increases to 15 per cent with aluminum. This means that the enameling of cylinders will reduce the temperature about 30 deg. fahr.

It strikes me that for purely military reasons air-cooled engines must be used in preference to water-cooled engines under certain conditions. In my estimation, the air-cooled aeronautic and automotive engine must be used for cross-country work over arid territory, in extremely cold climates and at high altitudes. According to a recent report of the Spanish fighting in Africa they are transporting the wounded over a stretch of 1800 km. (1118 miles) of hostile desert country, and in this work air-coo'ed engines are used almost exclusively due to the difficulty in obtaining water. I spent part of two winters in Siberia where, at times, the cold is intense. I found it necessary to make long trips by automobile. The low temperature around seaports did not bother us, as we had heated garages, but in the interior we had our troubles. After the introduction of air-cooled engines this difficulty was over. Even with air-cooled cars, trouble was experienced in starting in the morning, but starting on ether was usually successful.

For combat airplanes of the future and altitude work in general, I believe the air-cooled engine to be absolutely essential. The temperatures at an altitude of 35,000 to 40,000 ft. are extremely low. In descending from a great altitude the engine is ordinarily cut-out for a great portion of the time and the descent made by a series of glides. If anything goes wrong with the engine, unless all of the water in the cooling system is got rid of immediately, the cylinders will be cracked and the radiator injured before reaching ground.

CHAIRMAN HALLETT:—On all our supercharged airplanes we have what we call a dump-valve that makes it possible to release all of the water from the cooling system quickly. In case of engine trouble the pilot can dump the water out of the cooling system to prevent destruction by freezing.

S. D. HERON:—In reply to Mr. Lawrance it is admitted that the shrunk-in liner construction is much more satisfactory in sizes below 100-cu. in. capacity than in larger sizes. The British had, however, considerable trouble with this construction even in 67-cu. in. capacity cylin-

ders, difficulties with the liners burning away at the top, leakage of oil between the liner and the jacket and fractures of the jacket due to localized stresses at the holding-down-bolt bosses were experienced. Such failures were almost entirely a dynamometer condition produced by extended periods of full-throttle running at full speed, a test erring perhaps on the side of seventy, but which was considered necessary by the Royal Aircraft Establishment for the production of a reliable air-cooled cylinder.

Possibly Mr. Lawrance would find that some of the British experiences would be duplicated with his construction if submitted to 100 hr. of full throttle on a single-cylinder engine. The percentage of cylinders developing liner trouble was small, this practically never developing in flight. The lack of uniformity was, however, considered sufficient to condemn the construction.

I know of one R.A.E. 4E-cylinder that successfully withstood 350 hr. of full-throttle running. This goes to confirm the excellent results obtained by Mr. Lawrance with his shrunk-in liner construction. In spite of this, however, my experience even with cylinders of below 100-cu. in. capacity is that the thermal contact and thus the performance of the shrunk-in liner construction is a much more variable quantity than that of the screwed-in type.

Answering Mr. Hunt, it was not intended in the paper to indicate that cast iron is the best material for automobile-engine cylinder-construction and any lack of clarity causing the paper to be so read is regretted. However, in my opinion, cast iron is the most commercial material for car engine-cylinders, although I would not use it if cost was no object and cooling efficiency and high output were the main considerations.

The conclusions regarding the cooling efficiency of cast-iron cylinders are based upon the cast-iron R. A. E. 4D-cylinder and the B. S. A. car engine. The difference between the aluminum and the cast-iron R. A. E. 4D-cylinders is not excessive, although this cylinder size is beyond that for which cast iron is recommended. The figures given for the B. S. A. car engine are, I think, the best evidence in favor of cast iron for the air-cooled automobile-engine cylinder. That this car is able to cool efficiently without a fan, in spite of a fairly high weight-power ratio, speaks volumes for the possibilities of such cylinders. Mr. Hunt can readily confirm my remarks on the cooling efficiency of this engine by reference to reports of its performance in recent British competitions.

It is hoped that it will be possible shortly to furnish domestic data on the relative performance of cast-iron and aluminum air-cooled cylinders. The Air Service has under construction a 4½ x 5½-in. design on which comparative tests will be run with cylinders having cast-iron and aluminum heads, the construction being otherwise identical.

Replying to Mr. Crane, I would say that those who claim that the water-cooled engine will be superseded for aircraft use by the air-cooled type are rather wild optimists. Doubtless improvement in either type will but spur the other type to further improvement, paralleling the ceaseless competition that has gone on for years between the naval gun and armor plate. In my opinion, both types have advantages for particular applications. The air-cooled type has the advantage of a greater effective working temperature-range. That is of importance in extremes of climate. Furthermore, the air-cooled engine is not so vulnerable to gun-fire, since leaks in the ducts carrying the cooling medium do not cause almost immediate failure as in the case of a modern water-cooled engine. Water-cooling does not restrict the engine layout; whereas, air-cooling in the present state of knowledge does so very seriously. It is possible at present to air-cool successfully only a few types of layout; namely, radial, Vee, X and possibly line types.

Experience with large air-cooled radial engines in flight is as yet very limited, and it appears to be somewhat premature to draw conclusions regarding the relative head-resistance of this type with water-cooled engines of more conventional layout. Recent certified tests of European pursuit-planes, in which speed has by no means been the main consideration, have tended to shake the belief which was previously held in this Country to the effect that the large air-cooled radial engine causes excessive head-resistance.

In answer to Captain Snow, practically no experience in flight with the larger sizes of air-cooled cylinder has yet been obtained in this Country. The satisfactory experience of the Engineering Division with large cylinders on the dynamometer is somewhat limited and almost entirely confined to the type-J cylinder. In this latter design, 200 hr. of full-throttle testing has been obtained and considerable trouble with exhaust-valve breakage has been experienced, this being due in the main to the shock resulting from the somewhat crude exposed valve-operating gear, rather than from excessive temperature. A 50-hr. full-throttle run at 1650 r.p.m. has, however, been obtained on one exhaust-valve. During this run the only enforced stoppages were due to a broken push-rod and fouled spark-plugs. At the conclusion of this test the exhaust-valve, which was untouched throughout, showed some scaling on the stem and the neck and slight wear on the tip, the seat not having scaled in the least and being only very slightly pitted.

Preliminary tests on the type-I cylinder have demonstrated its inferiority in comparison with that typified by the J cylinder. The former type clearly demonstrates the disadvantages of the flat-head construction for air-cooled cylinders. This cylinder has shown markedly lower output, higher wall-temperatures and fuel-consumption than the type-J cylinder.

Flight tests of large American air cooled radial-engines should provide data on the relative head-resistance of this type in the near future. Should experience show that the radial engine is an undesirable type, satisfactory air-cooled V-type engines can certainly be produced. Allied experience on the Western and other fronts demonstrated that the air-cooled V-type engine is a satisfactory and reliable type, in spite of the fact that types used were fitted with what is now known to be very poor cylinder construction.

Mr. Clark also raises the question of the relative head-resistance of the air-cooled radial-engine and considers this to be excessive. In view of the paucity of evidence on this subject, I should be interested to have details of any comparative tests of air-cooled radial engines with conventional water-cooled types known to Mr. Clark. It is rather unfair to condemn the air-cooled radial engine on the score of head-resistance when so little real experience exists with this type and airplane designers have lacked an opportunity to develop efficient methods of fairing such engines.

The question of cooling on the ground with an air-cooled engine is really comparable to the similar problem of the water-cooled aircraft-engine; few of the latter will stand wide-open throttle on the ground for more than a few minutes without boiling. Past experience with air-cooled engines has shown that, with a cooling system designed to cool efficiently in the air, it is possible to run the engine full-open on the ground for about 2 min. and

then take-off without overheating. No useful purpose is served by running an engine full-open on the ground for a long period; opening full out for a minute or so to determine whether the engine will run up to speed is really all that is required.

The successful production of the later designs of the Engineering Division's air-cooled cylinder has been very largely due to the able assistance of Mr. Dix and his foundry staff. I wish to second Mr. Dix's remarks regarding the importance of the foundry in connection with air-cooled cylinders. If commercial success is to be obtained, ease of foundry production is essential.

In reply to Mr. Angle, I would say cast aluminum is at present the most practical material for aircraft cylinder-head construction as, for equal weight, greater total heat-conduction capacity in the walls and fins can be obtained than with any other present practical material. If materials other than aluminum be used for the cylinder-heads, the resulting design, if of equal weight, will be seriously lacking in stiffness to resist distortion due to the explosion pressure and temperature variations. The cast-aluminum head allows the production of a light engine, in which the port and combustion-chamber design is not cramped by considerations of ability to machine such shapes. Such considerations have to be given close thought in the built-up welded-steel construction used for water-cooled aircraft-engine cylinders, often to the detriment of the design. It is noticeable that water-cooled aircraft-cylinder design in this Country is steadily gravitating toward the aluminum head on account of the ease of production, apart from thermal considerations and questions of reliability.

For equal strength, some of the high-tensile aluminum casting-alloys are on a weight basis only inferior to forged alloy-steel, the disadvantages of which material for air-cooled cylinders are discussed in the paper. Preliminary investigations by the Engineering Division of the Y alloy have shown a tensile-strength at 600 deg. fahr. of 29,000 lb. per sq. in. in heat-treated sand-castings. The suitability of the alloy for cylinder construction has yet to be tested in actual service, but it has proved easy to cast into cylinder-heads.

In conclusion, I desire to amplify parts of the paper slightly, to avoid the possibility of misleading other workers on the subject. From the later experience of the Engineering Division it appears that the suitability of the copper-silicon alloys for cylinder-heads is open to question. One of the cylinders of this alloy recently tested developed stretching at the point of juncture with the steel barrel, apparently pointing to a very low elastic-limit at high temperature.

In the use of shrunk-in aluminum-bronze valve-seat inserts caution should be exercised in the amount of shrink used. As high shrinking-allowances set up excessive stresses in the cylinder-head, it seems that a suitable shrinking-allowance is 0.002 in. per in. of seat-insert outside-diameter.

Mention of the length of thread to be used in severed-in constructions was omitted in the paper. A thread length of not over one-quarter of the bore has proved satisfactory. Increasing the length of thread beyond this is liable to be productive of trouble, as the greater the length of the thread is, the greater will be the disparity of pitch between the steel barrel and the aluminum when heated-up, thus resulting in a poor thermal contact. Aluminum R. A. E. 4D cylinders with the liners threaded over the whole range of contact with the barrel gave exceedingly poor results, due to an almost entire lack of effective contact with the jacket and excessive oil-leakage and carbonizing.

It can be proved readily that, if the length of the United States Standard form thread be made 0.577 of the effective diameter, the head cannot be shrunk onto the liner or the barrel, because the effect of any increase in the pitch diameter due to heating of the head is counteracted by axial-pitch disparity.

MEMBERSHIP

To the Members of the Society of Automotive Engineers:

Each and every one of us appreciates the unusual conditions that have prevailed for some time, especially in the automotive industry, which affected the employment situation and naturally the opportunities of the Society of Automotive Engineers for getting new members, as well as to hold those members already within the fold.

You may be interested to know that in spite of many resignations, in spite of general conditions working against us for some time, the total membership in 1922 is somewhat in excess of the enrollment at the end of 1921.

A campaign to interest those who should in our judgment become affiliated is now in progress, with the idea of getting the names of good prospects among the production men, draftsmen, body engineers, etc.

The Membership Committee appreciates fully the hearty cooperation extended in our various efforts to interest additional worthy timber, but we would like at this time to emphasize the importance of continuing this good work so that we can make an exceptionally good showing for 1922.

The qualifications for full membership in the Society are specifically outlined in the application forms, and the Grading Committee and the Council which takes the final action desire as well as attempt to classify properly the applications received. We believe that those directly in charge of this work are taking a broader view regarding the qualifications for and the grades of membership. In addition, re-classification has had its effect, and with the untold advantages that accrue from an affiliation, combined with the rather nominal expense of being a member, it seems extremely possible that we, before the end of this year, should considerably increase our membership in all of the different grades.

It is only natural that applicants should desire full membership grade if at all obtainable, even though as associates they would secure all privileges except those of holding office and voting. Our desire is to classify the applicants so as to satisfy them, at the same time safeguarding the interest of what, in reality, is a strictly engineering society.

So, in soliciting applications we want you to feel, as we actually feel, that honest consideration is given each applicant's qualifications, as outlined in the applications. The references cited must of necessity be heard from before action can be taken. The recommendations of those given as references have due weight with the Grading Committee as well as the Council.

Let us all get intensely busy on this membership campaign and see if what we know to be the benefits of belonging cannot be passed on to many hundreds who we think should and could belong, putting up a figure covering a total membership of worthwhile chaps for the succeeding Membership Committee to shoot at for some time.

MEMBERSHIP COMMITTEE,
LON R. SMITH, Chairman.

New Principles in Rotative Balance

By Amos F. Moyer[1]

Minneapolis Section Paper *Illustrated with* Diagrams and Photographs

With the advent of high-speed machinery, the ordinary methods of rotative balancing were found insufficient. Rotative bodies that had been given the most careful static or standing balance would vibrate seriously when running, because of an unbalanced couple consisting of two quantities of equal magnitude on opposite sides of, but displaced from each other along, the axis. Thus, a second consideration in rotative balance, called dynamic or running balance, was introduced.

Until the invention of the balancing machine that the author describes, there were no means for measuring directly the resultants for the two separate ends of a rotative body, but now these quantities can be measured directly and located without the necessity of separating the standing from the running balance. The new principles are demonstrated mathematically with the aid of diagrams, the balancing machine is illustrated and described, and comments are made to afford a correct conception of the subject of balance.

THE need of balancing rotative parts probably has been recognized to some extent since the invention of the first crude machines in which man caused a wheel to revolve on a shaft. If the wheel was not symmetrical in all respects and one side was heavier than the other, the labor required to revolve the wheel was increased and the first lesson in rotative balancing was forced upon primitive engineers. To overcome this difficulty, the equalization of weight as evidenced by the action of gravity upon the wheel in various angular positions was found to suffice and, with man's increase in mechanical skill, refinements of this process were developed and employed with a fair degree of success so long as the rotative body was not too large in dimensions or revolved at too high a speed.

With the advent of high-speed machinery, such as electric machines, centrifugal pumps, cream separators, steam turbines and automotive engines, these methods were found insufficient. Repeatedly, rotative bodies that had been given the most careful static or standing balance would vibrate badly when running. The only possible condition capable of producing vibration of a revolving body that is in static or standing balance is the state of an unbalanced couple, consisting of two quantities of equal magnitude on opposite sides of, but displaced from each other along, the axis. A familiar example of this is a two-throw crankshaft with the crankpins 180 deg. apart. Thus, a second consideration in rotative balance sometimes narrowly called dynamic or running balance was introduced.

It has been the almost universal practice in producing rotative or complete dynamic including static balance to obtain first a state of static or standing balance and then to determine the remaining couple of so-called dynamic or running-balance correction. This couple must be applied as two equal quantities in two artbitrarily selected planes of revolution; usually consisting of the two ends of the body. Obviously, the initial or static correction for standing balance could be applied in either or both of the same planes of revolution. In either one of these planes, there would then exist two corrections. A single correction in each plane of the proper resultant magnitude and position would necessarily produce the same result.

[1] M.S.A.E.—Chief engineer, Precision Balancing Machine Co., Minneapolis, and consulting research engineer.

New Principles

Until the invention of Dr. B. L. Newkirk, of the research department of the General Electric Co., there was no means available for measuring directly the resultants referred to for the two separate ends of a rotative body. Now, these quantities can be measured directly and located, without the necessity of separating the standing from the running balance. That one and only one correction is required in each of two arbitrarily selected planes of revolution, dependent only upon the state of unbalance of the body and the position of the selected planes, is proved by the following analysis:

Since elements of unbalance are of the dimension weight times the radius, which is proportionate to centrifugal force at a given speed of rotation, we can, for purposes of analysis, speak of any such element as unit weight existing at a geometric radius of the proper magnitude.

In Fig. 1, let the plane $X_{x_0}Y$ represent any longitudinal plane of the body containing the axis of rotation XX. Any point such as A may represent the position of unit unbalanced weight at the radial distance x_1A from the axis of rotation. Assume two longitudinal positions such as YY and y_1y_1 for the determination of two quantities x_0D and x_2C, resulting from x_1A. By moments, we can write the equations

$$x_2C = (x_1A \cdot YA) \div Yy_1 \quad (1)$$
$$x_0D = (x_1A \cdot y_1A) \div Yy_1 \quad (2)$$
$$x_2C + x_0D = x_1A \quad (3)$$

Equations (1) to (3) show that by the application of x_0D_1 and x_2C_1, the equals and opposites of x_0D and x_2C, the system will be in complete equilibrium both statically and centrifugally.

If the position YY is taken as a fixed center or axis of moments and the position y_1y_1 considered variable, the resulting quantity on y_1y_1 will be the intercept on the hyperbolic curve AC which has the equation $x\ y = k$; only one such curve containing the point A. Likewise, when y_1y_1 is fixed, there can be but one similar curve DA which determines the position of D on YY, so that the corrections required, x_0D_1 and x_2C_1, depend only on the magnitude of x_1A, the existing unbalance, and on the location of YY and y_1y_1, the assumed positions of correction. By summing algebraically similar values for any number of elements of unbalance existing in the plane

XY, it will be seen that two corrections of the proper magnitude at assumed positions will always suffice.

It can be proved that after the application of one of the required corrections such as x_2C_1, which balances x_1A about YY, a second center of moments can be chosen at any point not contained in YY, and the remaining correction required on YY will still be the equal and opposite of x_0D as evaluated previously. Also, it can be proved that this value and location of correction is the only means of balancing about the second center of moments which will establish complete equilibrium.

If, after the application of the quantity x_2C_1, which balances x_1A about YY, a center of moments such as y_2y_3 is chosen not containing the point C, the resultant R_y on YY will be:

$$R_y = [x_1A \cdot (y_1A + y_1y_2)] - [x_2C \cdot y_1y_2]_1 \div (YA + y_2A + y_1y_3) \qquad (4)$$

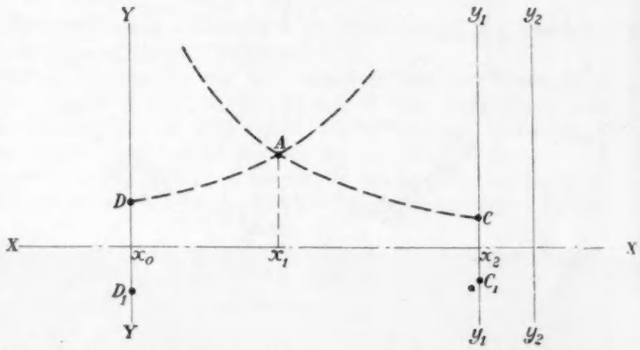


FIG. 1—DIAGRAM SHOWING HOW THE APPLICATION OF PAIRS OF EQUAL AND OPPOSITE QUANTITIES WILL CAUSE A SYSTEM TO BE IN COMPLETE EQUILIBRIUM, BOTH STATICALLY AND CENTRIFUGALLY

Where

$$x_1A = [x_0D \cdot (YA + y_1A)] \div y_1A$$
$$= [x_2C \cdot (YA + y_1A)] \div YA$$

Whence

$$x_2C = (x_0D \cdot YA) \div y_1A$$

Substituting in equation (4) the values of x_1A and x_2C in terms of x_0D, then expanding and collecting terms, we have

$$R_y = x_0D \qquad (5)$$

Equation (5) comes under the general theorem in mechanics that, after a solution by moments for one resultant force of a system, there will remain but one other force to establish equilibrium, and that force acts through the center of moments.

This shows that the resultant on YY after the application of x_2C is the same, irrespective of the location of the second center of moments. Here again the question holds only when the second correction is applied on the line of the first center of moments.

Fig. 2 is a three-dimensional representation of a body to be balanced, XX representing the axis of rotation. Let a center of moments be taken in any plane of revolution oo. In the plane of revolution aa, xA represents an element of unbalance and, likewise, in the plane of revolution bb, x_1B is an element of unbalance which may be of a different magnitude and in a different angular position about XX. The curves AC and BD are hyperbolas of the variety shown on Fig. 1, lying in the respective planes XXA and XXB and commonly asymtotic to the axis XX and the plane of revolution oo containing the center of moments.

In any desired plane of revolution cc, not coinciding with oo, the quantity x_2C has a moment about oo equivalent to xA. Likewise, x_2D is an equivalent of x_1B. The

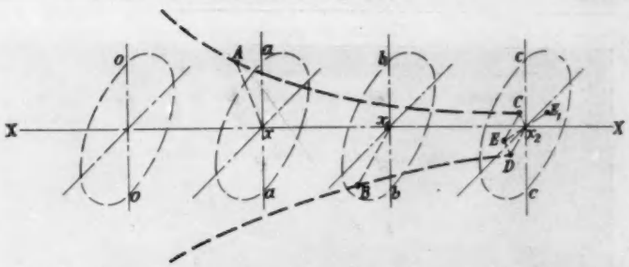


FIG. 2—THREE-DIMENSION DIAGRAMMATIC REPRESENTATION OF A BODY TO BE BALANCED

resultant in cc of x_2C and x_2D will be x_2E and both xA and x_1B can be balanced about oo by applying x_2E_1 equal and opposite to x_2E.

By a similar construction, taking a second center of moments in the plane cc, there can be evaluated the resultant in oo, which will be of a different magnitude and angular position from x_2E. It is also true that, after the application of x_2E_1, there will be only one resultant of unbalance lying in the plane oo, irrespective of the location of the second center of moments, and the application of the proper correction in oo will be the only means of obtaining complete equilibrium.

When oo is fixed with reference to aa and bb, changing the position of cc effects a variation in the magnitude of x_2E according to the same hyperbolic equation, but does not alter the angular position in the plane cc. The magnitude of the correction required in oo, and usually also its angular position, will be dependent upon the position chosen for cc. Likewise, with cc fixed, a change in the position of oo will affect the magnitude, and usually the angular position of x_2E_1 also.

As definitely as a multiplicity of quantities may exist in the plane Xx_oY of Fig. 1, and give but two resultants at the respective centers of moments, each being the algebraic sum for all quantities, the three-dimensional body of Fig. 2 requires but two corrections, each balancing the geometric resultant of all quantities referred to common centers of moments.

Actually, the centers of moments may take the form of pivoted supports, and the measurement and location of the resultants about these supports will complete the determination of corrections required to place the body in absolute rotative or complete dynamic balance, which is

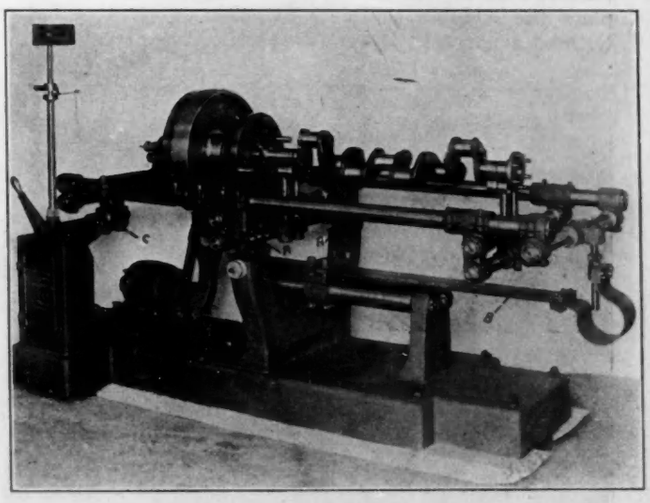


FIG. 3—A RECENTLY DEVELOPED MACHINE FOR DETERMINING THE BALANCE OF A ROTATING BODY

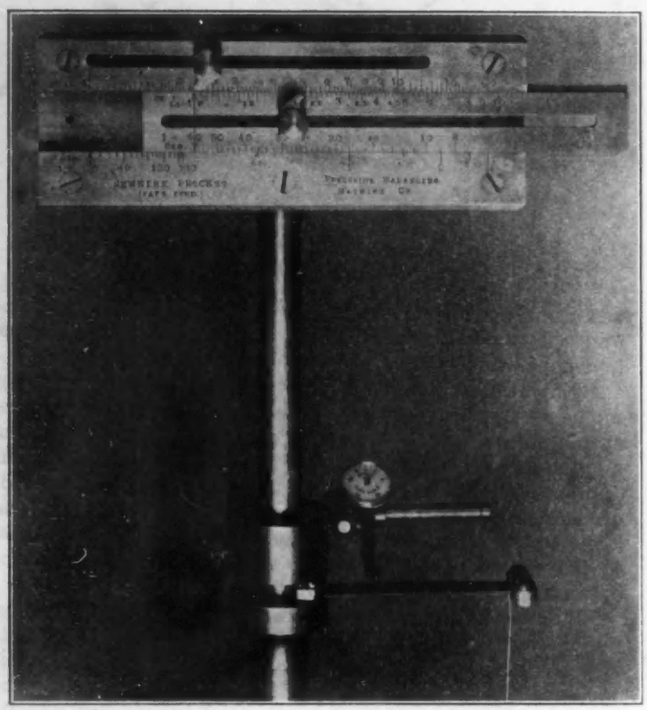


FIG. 4—APPARATUS FOR DETERMINING THE AMPLITUDE OF OSCILLATION

the state of complete equilibrium with respect to centrifugal force.

THE BALANCING MACHINE

Fig. 3 illustrates the precision balancing machine, the joint design of F. McDonough and myself, constructed under the Newkirk inventions. A frame is incorporated pivoted at *AA*, which supports the work in the desired positions to bring the selected planes in coincidence with the pivots or centers of moments. In this position the correction required in the overhanging end of the work is determined while revolving, and the ends of the work are then interchanged for determining the correction required in the plane initially over the pivots. These two corrections, at their respective angular positions, will place the body in complete dynamic or rotative balance without separately determining static balance.

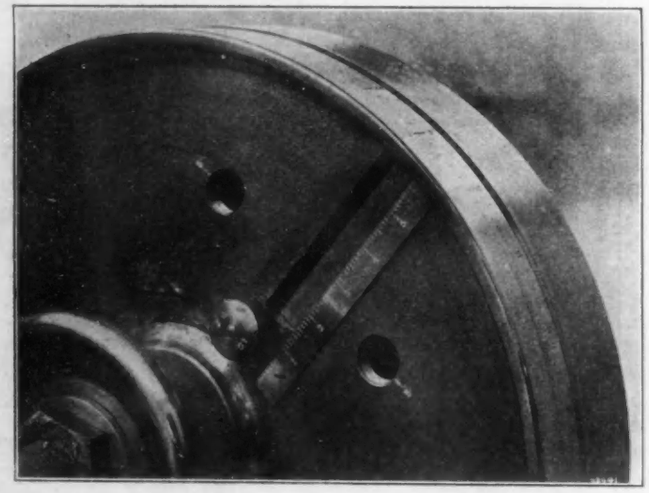


FIG. 5—STANDARDIZED WEIGHT IN THE HEADSTOCK OF THE MACHINE

The method of measuring the magnitude of a correction and the essential features of the machine for so doing are as follows: All revolving parts are ball-bearing mounted, including the rollers that carry the work. The frame is controlled in its position about the pivots *AA* by the main cantilever spring *B* so that, when the lock *C* is released, a free oscillation can occur in a vertical plane about the pivots *AA*. This suspension is so deli-

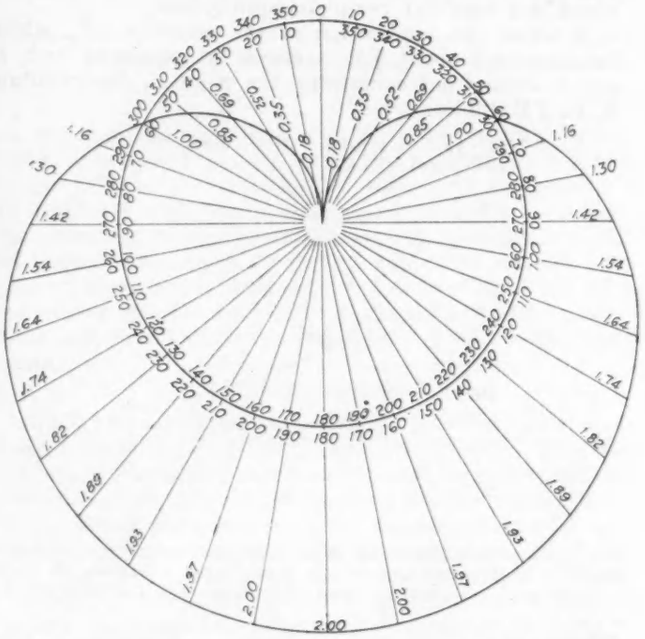


FIG. 6—POLAR DIAGRAM SHOWING THE ANGLE AT WHICH THE CORRECTION WEIGHT MUST BE APPLIED TO SECURE BALANCE

1—Observe the Greatest Amplitude of Vibration Obtained from the Freely Rotating Work
2—Move the Correction Weight from Zero the Proper Amount, Depending on Calibration, for This Amplitude and Observe the Second Amplitude
3—Divide the Second Amplitude by the First Amplitude, Expressing the Ratio as a Decimal
4—On the Chart of Angles Find Where Radius Equals the Ratio Determined and Turn the Correction Disk to This Angle

cate that, although the combined weight of the parts carried on the frame is more than 500 lb., perceptible oscillations can be produced by blowing upon the apparatus with one's breath. The amplitude of oscillation can be observed on the dial indicator at the left of the operator, which is illustrated in Fig. 4.

The revolving parts of the headstock are coupled to the work, and they are perfectly balanced. To take a reading, the system is set into revolution at a speed slightly above the natural period or critical speed of the frame, 100 to 110 r.p.m., and allowed to slow-down only by the slight and constant friction of the ball bearings. As the critical speed of the frame is passed through, a maximum oscillation will occur which is directly proportionate to the resultant of unbalance in the overhanging end of the work. By a separately determined calibration factor, the correction in ounce-inches is known for the plane of a standardized weight provided on the headstock, as shown in Fig. 5. This is revised subsequently according to the ratio of the longitudinal distances from the pivots of the standardized weight and the plane of actual correction on the work.

To obtain the angular position at which this correction is required, the quantity is applied arbitrarily on the headstock at an assumed angle, and the system is speeded-up again and allowed to slow-down through the

critical speed as before. The second amplitude will differ from the first amplitude by a ratio dependent upon the angle between the point of arbitrary application and the point required. The trigonometric value of this ratio is $R = 2 \cos \frac{1}{2} (180 \text{ deg.} - A)$, where A is the required angle. This function, plotted on a polar diagram, is shown in Fig. 6, which can be used for ascertaining the angle after obtaining the ratio of the second amplitude to the first. The equivalent of Fig. 6 also is built into a special slide-rule which can be seen mounted on the instrument column in Figs. 3, 4 and 7. Scales also are provided here for employing the calibration factor and taking ratios; so, the operator is relieved of all computation. Lastly, the angle ascertained is set off on the headstock and the result is checked by another run.

Production Procedure

The production procedure of these steps is shown by these illustrations as follows:

Fig. 4 shows by the dial reading the amplitude of a first vibration due to unbalance of the work only, and the corresponding setting of the slide-rule; block F on the upper scale remaining at the calibration factor, and block 1 on the sliding scale being set to the dial reading. Setting the slider for multiplication, the number of ounce-

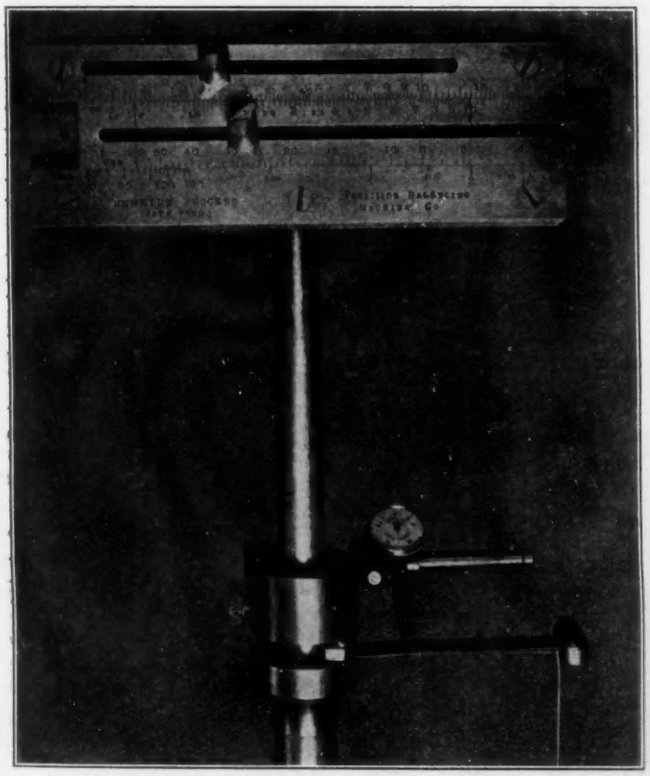


Fig. 7—Special Slide-Rule by Which the Angle at Which the Correction Weight Must Be Applied Can Be Calculated

inches of correction on the headstock is read on the upper scale above block 1. Fig. 5 shows the corresponding adjustment of the correction weight on the headstock with the disc remaining at zero-angle division. Fig. 7 shows the second amplitude and the corresponding setting of the slide-rule, with the sliding scale moved over until block 1, still set at the first amplitude, indicates the second amplitude on the upper scale, which is the position for division. The ratio of the second amplitude to the first amplitude might then be read at the left-hand

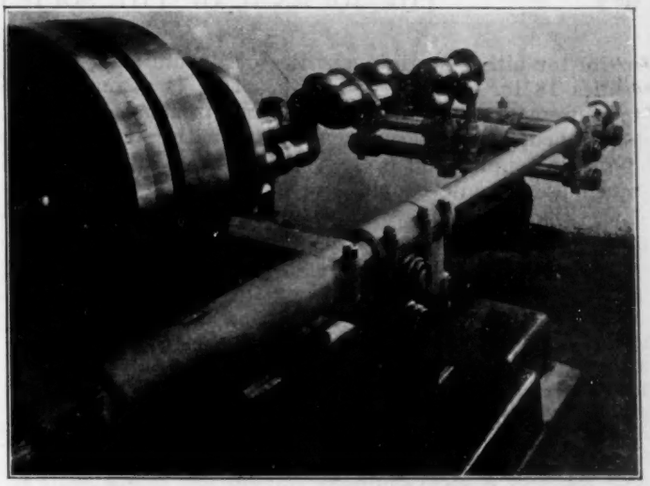


Fig. 8—View of Headstock Showing the Disc Turned to the Angle Indicated by the Slide-Rule as Being the Proper One To Secure Balance

index but, instead, the angle is read directly from the bottom scale. Fig. 8 shows the disc turned to the angle determined, and also gives visual evidence of a check result, as this series of photographs was made with an actually balanced crankshaft in the machine, that had been thrown out of balance by the application of a weight on the flange. Fig. 8 shows the self-determined alignment of the correction on the headstock with the weight on the flange; both weights lining with each other since they are on opposite longitudinal sides of the pivots.

Fig. 9 represents a cut-meter, a production instrument used with this machine on certain classes of work such as conventional six-throw crankshafts. By setting the blades to the quantity and angle determined as balancing-machine readings, the relative depths of cut required to remove from adjacent corners of the crank forging are read directly from the blade intersections with reference to the parallel rulings on the dial.

Accuracy and Rapidity of Measurement

The accuracy of measurement made with this machine can be guaranteed when appearing perfect within 0.2

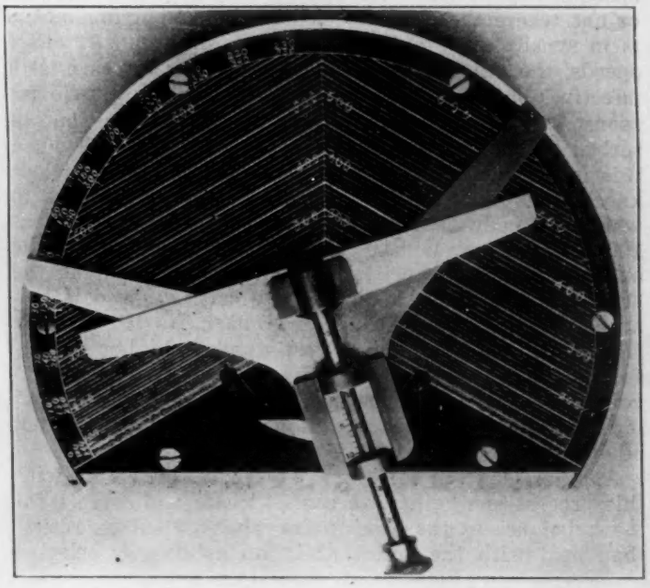


Fig. 9—Cut Meter That Indicates the Amount of Material That Must Be Removed from a Crankshaft To Secure Balance

oz-in. for either static quantities or dynamic couples on bodies 18 in. or more in length. This is a much finer measurement than commercial requirement demands. Short bodies, such as flywheels, are within 1 oz-in. for dynamic couples and 0.2 oz-in. for static values. Inasmuch as dynamic couples are of the dimension weight times the radius times the axial distance between planes of application, the above accuracy for flywheels is in every respect as fine as for longer bodies, such as multiple-throw crankshafts.

The machine is universally adjustable for any size of work up to a 24-in. swing and 32 in. between bearings. The accuracy above specified would suffice in most cases for rotors as light as 15 lb.; and work up to 750 lb. can be handled in the same machine, thus affording a combination of exceptional range in balancing facility.

The rapidity with which measurements can be made is evidenced by the fact that the process is definite. It leads by successive steps to the result, which is independent of any personal skill or knack on the part of the operator, and eliminates experiment. Determinations are made at the rate of 10 to 15 per hr., depending upon the amount of error existing in the work and upon the accuracy desired. Marks placed on the work direct the operation of applying corrections, which can be done at any time later, and does not require any rechecking of the result. This rate of production is worthy of considerable note when it is remembered that the accuracy is within a small fraction of work regularly passed and at a slower rate under present factory conditions. In fact, it can be said truthfully that many balancing operations, as now employed in factories, are but very little better than none.

Misconceptions of Balance

In conclusion, reference should be made to several misconceptions that are prevalent and are related to the general subject of balance. First is the idea that a body may be in balance at one speed and out of balance at another speed. This conception has arisen from the evidence that objectionable vibration may occur at one speed, but not at some other speed. In such instances the speed of objectionable vibration is only a "critical speed," or one where the elastic period of the supporting means is in synchronism with the speed of rotation. At other speeds, the unbalance producing vibratory forces is still effective, but does not meet with a periodic elastic response. In other instances, vibratory forces may be absorbed by the structure up to a certain limit and, when this is exceeded due to an increase in the speed, violent knocking or rattling may result. To the question as to whether a body balanced at a low critical speed such as 100 to 110 r.p.m. will be balanced at higher speeds, the answer is that the critical speed is a function of the support and a body balanced at its critical speed is balanced at all speeds. Trials of crankshafts balanced on this machine and run on a test-stand at higher critical speed have proved this conclusively, as does also the foregoing mathematical deduction. The use of a low balancing-speed has the added advantage that the body will not be distorted by centrifugal force.

Another question sometimes raised in connection with this process is whether we cannot locate and correct for the unbalance at the exact point where it exists, rather than deal with the resultant in an arbitrarily selected plane. It is neither necessary nor desirable to do this, as evidenced by the following: The engineering materials employed for all rotors are sufficiently rigid so that small corrections at desirable points may balance as resultants any errors existing elsewhere. Consider for a moment the metal composing a single crank-throw. If we were to measure the unbalance existing at this point and correct it by removing metal, the amount required to be removed would be the entire mass composing the member. Therefore, it is necessary that we correct for the resultant of the entire shaft, including all throws, and not for the errors existing at individual points in the piece.

The use of this machine does, however, open a wide field of research on the design of crankshafts, making possible the determination of centrifugal bending-stresses and the bearing pressures that result from them, and this would be of great assistance in problems of counterbalance and the like.

The Discussion

Chairman W. G. Clark:—After seeing the balancing machine in operation, I wish to state that the two things which impressed me as being new and absolutely reasonable are first, that this machine will balance a rotating part that is put in the rotating balance so that it absolutely eliminates all previous stages of balancing; and second that, contrary to our previous beliefs on the subject, it is not necessary to balance various parts of a crankshaft, because this machine eliminates all counterbalancing except two balancing operations in two separate and distinct points that comprise the entire balancing operation. This is radically different, according to my knowledge, from previous balancing operations.

A. F. Moyer:—With reference to the counterbalancing of the shaft, the point is simply that we can overcome any small variations that are due to the process of manufacture. A counterbalanced shaft may obviate a tendency to run in a bent condition, but that has nothing to do with balancing a shaft as a rotating body.

Chairman Clark:—I did not mean to eliminate counterbalance. I meant external counterbalance after the shaft is forged.

Mr. Moyer:—Only two points are necessary.

Chairman Clark:—That is my meaning.

A. W. Scarratt:—I attended the demonstration of the balancing machine and certainly was very much impressed with it. To my mind, it is the best balancing machine that has ever been developed. The engineers of the Society, especially, will be very much interested in getting first-hand information regarding it.

J. L. Mowry:—Will Mr. Moyer restate the application of the hyperbolic law, which he began with?

Mr. Moyer:—This is a simple matter of computation by moments. In other words, a quantity existing at one distance from the center of moments will have the same effect as a smaller quantity farther from the center, in inverse proportion, and the same effect as a larger quantity nearer the center. The algebraic expression of this gives the equation $xy = k$, which represents an hyperbola according to analytical geometry.

E. R. Greer:—Is there only one hyperbola that can pass through a given point?

Mr. Moyer:—Yes, when referred to a given set of axes, only one hyperbola can pass through a given point.

Coming Meetings of the Society

THE DETROIT PRODUCTION MEETING

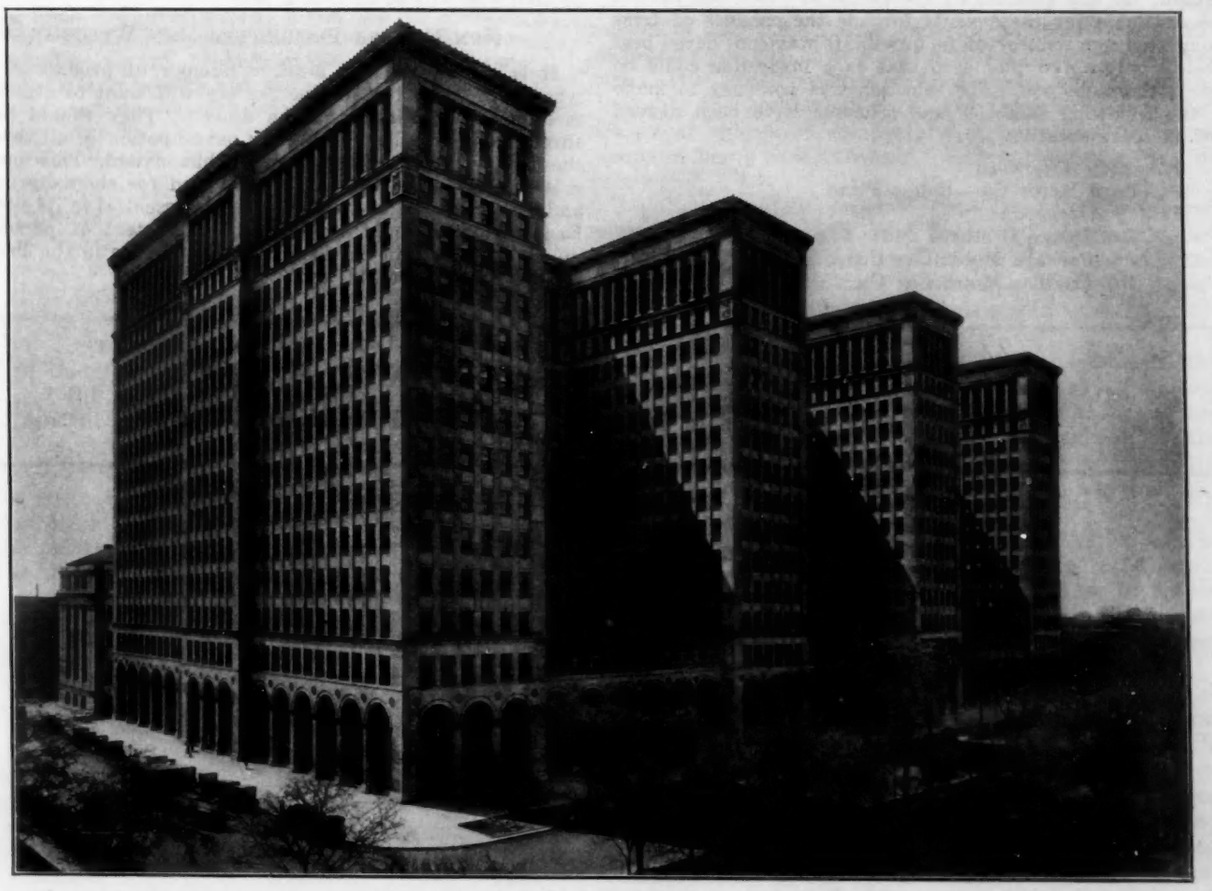
THE production executives and factory men of the automotive industry will hold their first meeting of national scope in Detroit, Oct. 26 and 27. This meeting has been arranged by the Society to bring the advantages of the business or professional meeting to the producing arm of the industry. Automotive sales, service, engineering and administrative conventions have been conducted in an organized way for many years. The production department alone has been unable to enjoy the benefits of cooperative reasoning and a closer social unity. It seemed logical that the automotive production men could be served by the Society of Automotive Engineers just as the designers and engineers have been. Thus we find the establishment of the annual Production Meeting and its location for 1922 appropriately set in the city producing the largest volume of automotive vehicles.

The meeting is expected to attract production and machine-tool men from all of the important centers of the industry. It will continue for 2 days and will include professional meetings, factory inspection visits and the Production Dinner. The final and definite details of the program will reach the members in a special issue of the *Meetings Bulletin* about Oct. 15. At least four factories will be visited during the two afternoons of the meeting. The two morning meetings will include papers and discussion covering a diversified group of production subjects, all of which will be found of value in practical production work. Little of a theoretical nature will be presented, it being considered far more important from the shop man's viewpoint to deal with actual factory experience. The following paragraphs deal with the individual features of the meeting.

The Professional Meetings

The professional meetings will be held in the General Motors Building on the Grand Boulevard near Woodward Avenue. The building may be reached from the center of the city by either the Woodward Avenue surface car or the Second Avenue motorbus line. The meetings will start promptly at 10 o'clock on each of the two mornings. There will be about five papers presented in each meeting with periods after each paper for questions and discussion. All of the papers have been written by members of the production staffs of automobile building plants. The program was intentionally limited to this group of men by the committee in charge of papers. Although the names of all of the authors cannot be announced at this time, papers are assured from the Studebaker, Ford, Packard, General Motors, Maxwell, Wills and Willys-Overland organizations. There is a possibility that other names will be added to this representative list by the time the final program is published in the *Meetings Bulletin* previously mentioned.

The Meetings and Papers Committee composed of K. L. Herrmann, chairman, T. J. Litle, Jr., C. Harold Wills and F. A. Whitten has worked diligently to secure material for



Office Building of the General Motors Corporation, Detroit, in Which the Production Meeting of the Society Will Be Held, Oct. 26 and 27

presentation that will reward those in attendance with a fund of practical and valuable information. The subjects vary from a treatment of miscellaneous shop practices to the problem of labor control. The group-bonus plan of labor control promoted by the General Motors Corporation will be described and some of its accomplishments presented. Unusual experiences in the study of gear noise will be recorded by the Packard production men. The chairman, K. L. Herrmann, will read a very comprehensive study of gear tooth variations and their relation to noise. His experience represents that of the Studebaker Corporation of America. The highly competitive automobile market demands a continued reduction of production costs. This condition directs attention to the savings resulting from salvage work and a member of the Overland organization will talk on this subject.

Inspection methods, machining of splined shafts and tool costs are other matters on which papers are expected. The Maxwell production department will be represented with a paper on simplified tools for parts production, comparing machining, labor and overhead costs with those on similar operations where expensive equipment was used.

Arrangements have been made to serve lunch in a room adjacent to the meeting hall immediately following the close of each professional session. This will not only prove to be an accommodation to the members but the lunch period will serve as an appropriate time for personal chats and afford an opportunity for better acquaintance among the production executives. The charge for the lunch will be a nominal one.

The Factory Visits

The factory inspection visits will start from the General Motors Building at 2 o'clock each afternoon soon after the lunches are finished. The committee in charge of this phase of the meeting is composed of K. K. Hoagg, chairman, T. J. Litle, Jr., Howard A. Coffin, E. F. Roberts and George E. Goddard. It was realized by the committee that the limited time available for these visits forbade the conduct of trips through a large number of factories. It was considered best to select only a few plants so that each inspection could be made a thorough one. The selection was not easy to make but the following factories and schedule have been agreed upon as representative.

Thursday Afternoon
Ford Motor Co.—Rouge Plant
Friday Afternoon
(a) Dodge Brothers and Packard Motor Car Co.
(b) Cadillac Motor Car Co.

The Ford-Rouge plant is probably the most comprehensive of its kind in the world, embracing the production of raw metals, finished parts of all kinds and the construction of bodies. It will be necessary for the members to select which of the optional trips they wish to take on Friday afternoon. The Dodge and Packard factories are well known and both will be visited in one trip. The Cadillac factory represents the most recent practice in factory buildings, machine tools and equipment for it has been completed and occupied since the war. Members will be driven to the factories in cars provided by the companies visited. They will be conducted through the shops by members of each company's production staff who will be familiar with the various operations that are performed in the different departments of the plant and the machines that are employed for the purpose.

The Production Dinner

The Production Dinner will be held at the Statler Hotel, Thursday evening, Oct. 26, at 7 o'clock. Tickets for the Dinner may be purchased from the Detroit Section office of the Society in the Book Building or ordered by mail from the New York City office. All seats will be reserved, giving whatever preference there may be in accordance with the order in which the applications are received. All requests for tickets must be accompanied by a check to cover the cost of tickets ordered at $3.50 each. The Production Dinner will be strictly informal both in dress and atmosphere. It is intended as an occasion for the promotion of intimate friendships among the men who are responsible for the construction of motor vehicles and their parts. Only one dinner speech will be made other than the toastmaster's introduction. This speech will be inspirational and the committee may be relied upon to select an able talker with a message. Look for the *Meetings Bulletin* around Oct. 15 for the dinner details; meantime send along a remittance for your ticket so that you will be sure of a seat.

Non-Member Production Men Welcome

It is recognized that a large number of production men who are not members of the Society will want to attend the meetings, inspections and the dinner. They should be assured by the members that their participation in all three of these activities is not only welcome but invited. This meeting is a producers' meeting. It is intended for shop executives, and their presence in large numbers is essential to its success. Each member should cooperate to the extent of personally inviting the men in his factory to participate in the Production Meeting on Oct. 26 and 27.

COMING SECTIONS MEETINGS

Will Be Found Described in This Issue of THE JOURNAL on p. 380

Rear-Axle Gear Calculations by the Compressive-Stress Method

By JOSEPH JANDASEK[1] *Illustrated with* DRAWING

THE practice of checking the design of gears by the bending-stress method, now in common use, is shown to be merely guesswork, when the question of durability is involved. It is sufficient when the bending strength only is sought, but as the wear on the face of the tooth often is a source of more trouble than is breakage, the ability to resist crushing is the best measure of the tooth's capacity. As the wearing quality depends upon the maximum surface-pressure, the size of gears must be based on the compressive stresses to which they are to be subjected. When the unit pressure for a given material is raised above a certain value, the wear of the tooth will increase rapidly. Consequently, it is important to know the limiting value of the unit pressure under which a gear will stand up.

Beginning with the theory of pressure between elastic bodies with curved surfaces, the author develops formulas for calculating the greatest allowable load on the pitch-line for spur and bevel gears. Incidentally attention is called to the variation of the capacity of pinions, when meshing with a large and with a small gear and, similarly, of ball bearings, when the diameter of the balls and the size and shape of the races are varied.

The capacity and strength of gears with straight and helical teeth are investigated. Formulas for checking the pitch and for computing the number of teeth when the compressive and bending stresses are equal, the face of gears in contact and the pitch-diameter of differential gears and pinions are worked out. Examples are given showing the application of the formulas to the design of helical bevel and differential-gears.

IN present-day practice most gears with straight teeth are calculated, or rather checked, by the bending-stress method by which the maximum permissible load that will assure freedom from breakage of the teeth at the roots can be determined. As a rule, this is the only checking that the average gear-designer does. Such calculation, however, is merely guesswork, as will be proved in this article, mainly because it is the wear on the face of the tooth and not the breakage at the root that causes the most trouble. It is a well-known fact that gears designed to give at least a reasonable amount of service do not break but wear out.

So far as tooth breakage is concerned the strength of gears calculated by the bending-stress method is sufficient for passenger cars as well as for trucks and tractors, for the rear-axle as well as for the change-speed gears. We cannot, however, say the same regarding the wear on the face of the tooth and it is only natural that the designer employing this method should not obtain the desired results on the first attempt. Then, of course, the process of redesigning, building and trying out the gears anew follows. This is not only expensive but requires time and some driving before the wearing quality of the gear can be ascertained; that is, whether the pressure on the face of the teeth is excessive so that backlash and noise will develop and result finally in the complete destruction of the mechanism, if replacements are not made in time.

The breaking load is merely a measure of the strength of the gear. The only true and rational measure of the capacity of gear teeth is the ability of the face of the tooth to resist crushing, or the resistance of a tooth to abrasion or wear at certain maximum permissible pressures or compressive stresses. Gear sizes must be determined on the basis of the stresses on the tooth face, that is, the working, wearing and noise-causing surface. The wearing quality of gear-tooth faces depends upon the maximum surface-pressure, provided the quality of the material, toughness, coefficient of friction and tooth action are constant. The value of this maximum permissible unit compression depends upon the ultimate strength, which, again, is closely proportional to the hardness. This is the reason the designer always specifies the hardness number to obtain the desired resistance to wear. The other properties of the material, such as toughness and the coefficient of friction, must be taken care of in the way that different unit surface-pressures, or compressive stresses, are computed in different gear materials, even when their hardness numbers are equal.

The relation of face hardness to wearing quality explains the great success of case-hardened gears. They possess a hard and strong case of extremely high ultimate-strength but have a soft and comparatively weaker core. The bending-stress method takes into consideration only the low-carbon core; but the tooth faces that are under very high compressive-stresses are also much stronger, being case-hardened. Hence, the design can be successful.

Another example proving this theory is tempered gears. They are never used for rear-axle gearing, because they wear out; that is, the tooth faces cannot stand the pressure. Yet we know that tempered steel possesses a considerably higher ultimate-strength than the soft core of the low-carbon case-hardened tooth

It is apparent that it is the compressive-stress on the tooth face that determines the capacity of gears and not the bending-stress at the root of the tooth. The compressive-stresses in gear teeth are determined by the area of the contact surface, which is dependent upon the curvatures of the gear and pinion teeth and the face over which the load, or pressure normal to the tooth, is distributed. This contact surface carries the load. The pitch should be sufficient only to resist fracture. A larger pitch is uneconomical, as there is no increase of power-transmitting capacity. As the number of teeth decreases, the uniformity of motion decreases and the consequent noise increases.

It is known that there is a certain value of the unit pressure for a given material of a definite hardness, above which the wear will increase rapidly and the life of the gear will be shortened greatly. On the other hand, when the unit pressure is kept sufficiently below this critical value, the gears stand up well and have a long life. Consequently, it is not the amount of wear in a definite time that we want to know but the limiting value of the unit pressure on the tooth face under which the gear will stand up.

[1] Engineer, Olds Motor Works, Lansing, Mich.

The wearing quality of the final-drive gears can be slightly improved by allowing the teeth to find their proper bearing surfaces by starting under a partial load only. Mounting the gears on rigid shafts in rigid housings is also necessary. The driving pinion should be provided with a bearing on each side to ascertain the correct and efficient mesh along the whole length of the tooth face. An overhanging pinion is usually out of alignment, especially under heavy pulls, because of the large bending-moment on the shaft, and is bound to wear-out soon on account of the increased compressive-stresses. Strong housing must be provided, with easy and accessible gear and pinion adjustments. Bearings ought to be rather oversized to assure good and lasting contact.

The propeller-shaft brake or the transmission brake ought to serve only as an emergency brake because the action of changing the function of a pinion from that of a driving member to a driven one is very severe and hard on the gears and bearings. Using the engine as a brake is also an expensive practice for the same reason.

Spur and Bevel Gears

In the foregoing I have shown that the wear of gears depends upon the unit compressive-stresses on the contact surface of the tooth. To determine this contact area, or rather the maximum compressive-stress, we must begin with the theory of the pressure between elastic bodies with curved surfaces. In the following I have derived formulas for the greatest allowable load on the pitch-line.

The capacity in pounds of spur gears with straight teeth is

$$W_c = [10^{-5}C^2pf]\ [n/(1+a)\,] \qquad (1)$$

The capacity of bevel gears with straight teeth is

$$W_c = [10^{-5}C^2pf]\ [n/\sqrt{(1+a^2)}\,]B \qquad (2)$$

Further, it is known that the strength of spur gears with straight teeth is

$$W_b = Spfy \qquad (3)$$

The strength of bevel gears with straight teeth is

$$W_b = Spfy_1B \qquad (4)$$

where B is the reducing factor and equals

$$B = 1/3 + l/3L + l^2/3L^2 \qquad (5)$$

$a = d/D$ = value of the gear-ratio, pinion to gear, which must be added for external gears and subtracted for internal ones

C = the maximum allowable compressive-stress on the tooth face at the pitch-line in pounds per square inch for a given speed, V

f = the face of gears in contact in square inches

L = outer pitch cone radius for bevel gears

l = inner pitch cone radius for bevel gears

n = number of teeth on the pinion

p = circular pitch in inches

S = the maximum allowable bending-stress in pounds per square inch

W_c = the maximum tangential force in pounds at the pitch-diameter with regard to the compressive-stress at the pitch-line, assuming that only one pair of teeth is in mesh at a time

y and y_1 = factors depending upon the number of teeth

From the equations (1) and (2) it can readily be recognized that the capacity of a pinion according to my compressive-stress method depends not only upon its own dimensions but also upon those of its mating gear.

The same pinion meshing with a large gear possesses a greater capacity than when meshing with a small one, this being the influence of ratio a. Placing the capacity W_c of a spur gear, meshing with a gear of the same size, equal to unity, I have found that the same gear possesses a capacity 2.7 times greater when in mesh with an internal gear having the ratio of 1 to 4. The total difference in capacity, therefore, can be 270 per cent, if the influence of the mating gear is neglected. Hence, it is evident that when bending stresses alone are used for determining the capacity of gearing the process is merely guesswork. It might or might not give the results desired depending upon the factors used. These include gear-ratio, number of teeth, quality of the material, workmanship and exactness of tooth profile.

We find the case to be exactly the same with ball bearings where the capacity depends not only upon the diameter of the balls but upon the size and shape of the races. But the strength of a pinion calculated solely upon the basis of bending stresses depends upon its own dimensions only and remains constant whether the pinion meshes with an external gear, rack or an internal gear of any size.

According to the same theory of maximum surface pressures I have found the formula for helical spur-gear capactiy to be

$$W_c = [10^{-5}C^2pf]\ (n/[(1+a)\cos^2 H]) \qquad (6)$$

where p is not the normal but the circumferential circular pitch and H is the angle of helix.

As it is not possible to calculate the strength of a helical tooth by bending stress owing to the complicated shape of the tooth, the shearing stress K of a tooth at a pitch-line is taken as a measure of the gear strength. Hence,

$$W_s = 0.4pfK \qquad (7)$$

Before we step to the calculation of helical bevel-gear capacity let us recall a few facts about this type of drive.

There is practically only one type of final-drive in use for passenger-car axles and this is the helical bevel-gear, shown in Fig. 1. This drive is being used on almost all car models now on the market. The main advantage of this gear is in noiseless operation at all speeds. It permits the use of a smaller number of teeth than can be used with straight bevel-gearing, where the number of teeth must not drop below a certain minimum, usually 12 because, as the number of teeth decreases, the non-uniformity of motion and, consequently, the noise, increase rapidly. Helical gears also wear evenly along the tooth flank so that such gears, even if partly worn, transmit the motion uniformly and do not get noisy as soon as straight bevel-gears. For the same reason the increment of load due to the irregularity of impulse cannot become dangerous even at the highest speeds. Thus, the capacity of the gear is increased and a finer pitch can be used.

The angle of helix should be such as to allow sufficient angular advance, corresponding to the length of the gear face, and should be from 10 to 20 per cent greater than the circular-pitch.

The high-speed engines used on automobiles require comparatively high gear-reduction, that is, from 3½ to 1 to 4¾ to 1. Helical bevel-gears have made it possible to obtain this higher reduction in a single step without the danger of non-uniform and noisy operation. In reference to these large gear-ratios it should be noted that the accelerating ability is increased at the expense of the fuel economy. Economy demands the conservation of fuel. Consequently, a smaller top gear-ratio should be used. This small gear-ratio could be easily combined with either a geared-up fourth speed in the transmission or still better by employing a two-speed rear axle. It is interesting that on one side there is so much talk about increasing engine economy by 0.1 per cent while on the other side such well-known principles as those mentioned remain practically overlooked.

Helical Bevel-Gears

Helical bevel-gear drives with pinions having as few as six teeth have been produced successfully in extreme cases. With a small number of teeth the pinion must be made integral with the shaft, which is, however, the best practice anyway, as it does away with the troublesome key in the shaft, especially when the transmission brake is used.

As to the strength against fracture, it is usually assumed that a helical bevel-pinion of a definite diameter and a given pitch is capable of transmitting the same power at a certain speed as a straight bevel-pinion of the same diameter, pitch and face, although it is plain that the tooth action is different because the teeth of the helical bevel-pinion are curved and at an angle to the gear axis. Mathematically, such an assumption never has been proved. In fact, the total normal load on teeth and the end-thrust are considerably greater with the helical than with the straight pinion. Finally, the factor depending upon the number of teeth is absolutely unknown. On the other side, there is always a pitch-line contact somewhere and more teeth are in contact at one time. If the helix advance,

$$h = ftgH$$

is greater than the circular-pitch, by which is meant not the normal but the circumferential pitch, then the arc of action always includes at least one more tooth per gear than in a similar straight bevel-set.

In the foregoing I have demonstrated that the formulas (2) and (4) determine the capacity and strength of bevel gears with straight teeth with respect to their compressive and bending stresses. However, in the case of helical bevel-gears of comparatively small diameter, low peripheral velocity and small number of teeth, a further simplification can be made.

On the basis of the compressive-stress principle, I have derived the formulas for helical bevel-gear capacity, which are exact in all factors simply because the curvature of any tooth profile always is known with mathematical exactness. We have for the capacity of helical bevel-gears

$$W_c = [10^{-6}C^2pf](n/[\sqrt{(1+a^2)}\cos^2 H])B \qquad (8)$$

The factor $\sqrt{(1+a^2)}$ can be left out, because its value for large reductions in the case of rear-axle gearing is equal to almost unity. However, for racing cars with small ratios this factor cannot be omitted. The formula for helical bevel-gears with large ratios then will read

$$W_c = (10^{-6}C^2pf)\,(n/\cos^2 H)\,B \qquad (9)$$

As the helix angle is always around 30 deg., the maximum permissible compressive-stress, $C = 110{,}000$ lb. per sq. in., and the reducing factor, $B = 0.75$, or close to it, we can obtain a very simple formula for quick, approximate calculations.

$$W_c = 125pfn \qquad (10)$$

The above formulas constitute the only dependable way known for calculating the dimensions of helical bevel-gears.

For checking the pitch of helical bevel-gears I use the formula

$$W_s = 0.4\cos H(KpfB) \qquad (11)$$

Here it is assumed that the shearing stress is a measure of the gear-tooth breaking-strength, as it is known in the case of herring-bone gears. The value 0.4p represents the thickness of a ring-gear tooth on the pitch-line and p is not the normal but the circumferential pitch, $\pi d = np$.

For quick, preliminary calculation this formula can be simplified to

$$W_s = 0.26\,Kpf \qquad (12)$$

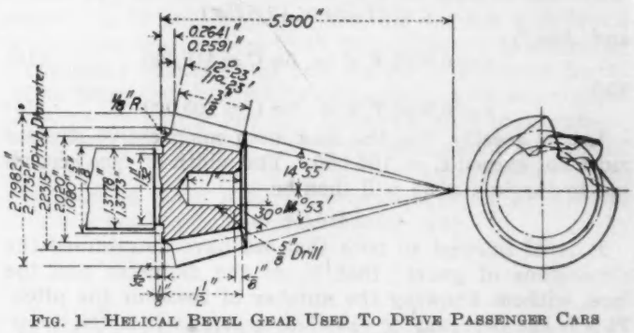


Fig. 1—Helical Bevel Gear Used To Drive Passenger Cars

Placing, in the equation, $W_b = W_c$

$$0.4\cos^3 HK = 10^{-6}C^2n$$

we get

$$n = 0.4\,(10^6\cos^3 H\,[K/C^2]) \qquad (13)$$

Thus we recognize that by keeping the stresses K and C constant, we can, within given limits, decrease the number of teeth n by increasing the helix angle H. The smaller the number of teeth, the larger will be the angle H for the same stresses.

Another way to obtain a smaller number of teeth n is to keep the stress C constant and decrease K. In practice the helix angle ranges from 28 to 32 deg., with an average of $H = 30$ deg.; the ratio of face to pitch, $b =$ 1.5 to 1.8; the number of teeth, $n = 7$ to 12; the ratio $f/L = 0.25$. Hence, $B = 0.77$.

The pitch-diameters of bevel gears are limited, because of the required ground-clearance, to about 10 in. for the lightest cars, of some 2500-lb. total weight, complete, ready for the road; 10½ to 11 in. for medium-sized cars; and 11 to 12 in. for large cars.

The maximum allowable compressive-stress is $C =$ 105,000 to 110,000 lb. per sq. in., according to the workmanship, at a speed of about 750 ft. per min., calculated on the basis of a piston speed of 1000 ft. per min. and a direct drive; and the maximum allowable shearing-stress, $K = 4000$ to 5800 lb. per sq. in., both stresses being figured for a 3½-per cent nickel-steel case-hardened pinion. The mating gear can be made from 1¼-per cent nickel or chrome-nickel steel, case-hardened. Fig. 1 is a sample drawing of a helical bevel-pinion with the necessary dimensions and specifications.

Application of Formulas

Example 1. — To determine the size of helical bevel-gears for a passenger-car rear-axle under the following conditions:

Engine, 3¼ x 5 in., six-cylinder
Gear-ratio, 1 to 4.5
Engine speed, N, at a piston speed of 1000 ft. per min. = 1200 r.p.m.
The horsepower on the basis of the National Automobile Chamber of Commerce formula = 25.35
The corresponding torque, T = 1330 in-lb.

Solution.—First, we have to decide the maximum diameter of the ring gear. Because of the road-clearance we select $D = 10¾$ in. when used for medium-sized cars. The pinion diameter will be $d = 10.75/4.25 = 2.39$ in. According to the formula (10) we have

$$W_c = 125\,pfn$$

However

$$np = \pi d$$

and

$$W_c = 2\,(T/d)$$
$$W_c = 125\pi df \qquad (14)$$

Hence, we get

$$2(T/d) = 125\pi df$$

and for f we have

$$f = (T/d^2) \times (2/125\pi)$$

and, finally,

$$f = 0.0051\ T/d^2 \text{ in., for } C = 110{,}000 \qquad (15)$$

and

$$f = 0.0056\ T/d^2 \text{ in., for } C = 105{,}000 \qquad (16)$$

Let us specify that the maximum compressive-stresses must not exceed $C = 105{,}000$. The width of face according to formula (16) will then be

$$f = 1\ 5/16 \text{ in.}$$

It is of interest to note that we have determined the dimensions of gears; that is, of the diameter and the face, without knowing the number of teeth or the pitch. This is the best way to calculate gears, as it is the diameter and face combined that carry the load.

Now we can calculate the number of teeth of the pinion, using formula (13)

$$n = 0.4\ [10^{-5} \cos^3 H (K/C^2)]$$
$$= 0.4 \times 10^{-5} \times 0.65 \times 4000/105{,}000^2$$
$$= 9.44$$

Thus, for the pinion we have $n = 10$ teeth, and for the gear $n_g = 45$ teeth. The pitch, not normal, will be

$$P = (\pi d) \div n = 0.75 \text{ in.}$$

Instead of using equation (13) to calculate the number of teeth, it would be better to use the formula (11) and determine the necessary pitch directly.

$$W_e = (0.4\ K \cos H)\ (pfB)$$
$$1110 = 0.4 \times 4000 \times 0.866 \times p \times 1.3125 \times 0.78$$
$$p = 0.786$$

We find that the nearest number of teeth is $n = 10$, and that the shearing-stress will be slightly increased in proportion to the reduced pitch, $K = 4190$ lb. per sq. in., which is perfectly safe.

Now we must check the helix angle, H, for the necessary overlap. Since the circular pitch $p = 0.75$, the advance of helix

$$h = f\ tg\ H$$
$$= 1.3125 \times 0.5774 = 0.758 \text{ in.}$$

This leaves a comparatively small overlap, but nevertheless it is sufficient. A slight increase in the angle to say 32 deg. or, still better, an increase in the shearing stress K and the number of teeth on the pinion to say 11, would give a better overlap. It is preferable to have an overlap of from 10 to 20 per cent. Shearing-stresses up to $K = 5800$ lb. per sq. in. are safe if the workmanship and the adjustment of the gears are correct. By using a higher shearing-stress, up to certain limits, we obtain a finer pitch, more teeth, a greater overlap, a more uniform motion and noiseless operation.

We have now to check in our example the values B, K, and C, from the original formula (9), especially when the rounding of the face width and the original value of the coefficient B were much different. In our example the difference amounts to very little.

Differential Gears for Passenger Cars

In calculating the dimensions of differential gears with respect to the breaking stress, we should bear in mind that the gear dimensions must depend upon the maximum torque at the rear axle at low gear. However, to make certain that the differential gears will not wear-out too soon and to keep on the safe side we should check them for compressive-stresses to ascertain how much service can be expected.

The following data are for a good, compact design of differential gears:

Number of teeth of pinion, $n = 10$ to 11
Number of teeth of side gear, $n_g = 18$ to 20
Ratio of face to cone radius, $f/L = 1/3$ *to* $3/8$
Ratio, $l/L = 0.67$ to 0.625
Coefficient, $B = 0.71$, when $f/L = 1/3$
Coefficient, $B = 0.67$, when $f/L = 3/8$
Compressive-stress on the direct drive at a torque calculated on the basis of National Automobile Chamber of Commerce horsepower formula, $C = 120{,}000$ to 130,000 lb. per sq. in.
Bending stress on direct drive, $S_d = 15{,}000$ to 16,500
Bending stress on low speed at ratio of 3.3 to 1 in the gearbox, $S_l = 50{,}000$ to 55,000

In the foregoing example we start with the formula (2), which gives the capacity of straight bevel-gears.

$$W_c = [10^{-5} C^2 pf]\ [n/\sqrt{(1 + a^2)}]B \qquad (2)$$

Further,

$$W_c = T/Dm$$

where

D = pitch-diameter of side gear
m = number of pinions, usually four

Substituting $\frac{3}{8}\ L$ for f, 0.67 for B and aD for d, we obtain

$$L = \sqrt{[(D/2)^2 + (aD/2)^2]}$$
$$= D/2\sqrt{(1 + a^2)}$$

and

$$f = 0.1875D\sqrt{(1 + a^2)}$$

Further, $n\ p = \pi\ d = \pi\ a\ D$ and for $C = 120{,}000$ we will get

$$D = 0.20\sqrt[3]{(T/ma)} \qquad (17)$$

For our case, $a = 10/18 = 0.55$, selecting the smallest possible number of teeth, and $m = 4$.

Then from formula (17) the pitch-diameter, $D = 3.62$ in.

We will take $D = 3.6$ in. for the gear and $d = 2$ in. for the pinion. Knowing the diameters we find the width of face from equation (2) to be $f = 9/16$ in., and the diametral pitch, from equation (4), to be 5 — 7, for stub teeth.

Maag Gears

An interesting example demonstrating the possibilities of improvement along the line of gear design is found in Maag's gears, which proves that research work in this field, when properly conducted by able engineers, is bringing forth remarkable results. Maag's gears represent the most scientific gear system of the present time.

Endeavoring to obtain gears of great durability and noiseless operation even at large reductions, the Swiss engineer Maag based his system on the well-known involute curve. The tooth action of two involute gears remains mathematically correct at different center-distances and is independent of the pitch-circle. By increasing the center-distance the tooth action remains correct, the angle of the action only being changed. The backlash, of course, then increases, but this can be corrected easily by increasing the thickness of the pinion teeth, a feature to be desired. Different involute angles, ranging from 15 deg. at small reductions to 25 deg. at the largest ones, are used for different gear-ratios. In this way the tooth action and the proportion of roll to slide for each particular ratio is much more favorable than when the same angle is used for all ratios. At present we use a 20-deg. pressure-angle for spur as well as for bevel gears of any reduction for the sake of interchangeability. However, for final-drive and for large production this interchangeability is of no importance and special gears can be used.

Maag's pinion teeth are strong and noiseless and the gears have a greater capacity owing to the increased involute angles and the proportion of roll to slide. Hence the allowable compressive-pressures can be increased and

extremely high reductions are obtainable. All these features are very desirable in automotive gears and therefore the application of this or a similar system to automotive practice would result in increased efficiency, noiseless action, durability and greater power-transmitting capacity of gears.

In the foregoing I have demonstrated the application of my compressive-stress method, which is the only method of calculating the capacity of gears in connection with durability or wear. In the case of helical gears it is the only rational way of determining them at all. This method is of still greater value in making possible a ready investigation of a tooth of any form and affording a rational comparison of the merits of different tooth-forms from the standpoints of capacity and wear, especially where weight and size are of primary importance.

Compressive stresses on tooth faces and the ratio of roll-to-slide action are the principles that require study and must be taken well into consideration if we wish to obtain a really efficient and durable gear.

LETTER BALLOT ON ADOPTION OF STANDARDS

THE proposed standards and recommended practices printed on p. 475 of the June 1922 issue of THE JOURNAL and approved by the Standards Committee at the meeting at White Sulphur Springs were approved by the Society members by the letter-ballot which closed Aug. 19.

The recommendation on Flywheel Housings, however, which involved increasing the minimum diameter and depth of the clearance space for crankshaft flywheel bolts, received 10 negative votes and as a result of the reasons submitted in support of these votes the Council voted to withhold it from publication in the S. A. E. HANDBOOK and to refer the recommendation back to the Engine Division for joint consideration with the Transmission Division.

The report of the Screw-Threads Division covering allowances and tolerances for screws and nuts taken from the report of the working committee of the Sectional Committee on Screw-Threads of the American Engineering Standards Committee was also withheld from publication in the S. A. E. HANDBOOK by vote of the Council. This action was taken because the Society had been informed by the American Society of Mechanical Engineers that at a meeeting on Sept. 15 the Sectional Committee proposed certain changes which affected in a general way the entire report of the Screw-Threads Division on Screw-Threads.

The complete vote on all of the recommendations considered at White Sulphur Springs is tabulated herewith. The first column gives the number of affirmative votes; the second column the negative votes; and the third column the number of members who did not vote either way.

	Yes	*No*	*Not Voting*
Tractor Drawbar Adjustments	91	1	210
Motor-Truck Front-Axle Hubs	137	2	163
Breaker-Contacts	157	0	145
Ignition-Distributor Mountings	157	0	145
Magneto Mountings	165	1	135
Starting-Motor Flange Mountings	166	0	136
Flywheel Housings	168	10	124
Leaf-Spring Steel	152	2	146
Steel Spring-Wire	158	0	142
Electric Incandescent Lamps	145	0	155
Electric Incandescent Lamp Voltage	150	0	150
Head-Lamp Illumination	142	0	158
Head-Lamps	143	0	157
Motorboat Lighting Voltages	113	0	187
Aluminum Alloys	120	1	179
White Bearing Metals	117	0	183
Wrought Non-Ferrous Alloys	113	0	187
Ball Studs	163	1	136
Lock-Washers	187	1	112
Passenger-Car Front Bumpers	147	1	152
Plain Steel Washers	185	0	115
Serrated Shaft Fittings	168	2	130
Rod-Ends	173	1	126
Tank and Radiator Caps	166	1	133
Top-Irons	106	0	194
Screw-Threads	192	0	108
Screws, Bolts and Nuts	194	0	106
Frame Brackets for Springs	146	2	152
Spring-Eye Bushings	154	2	144
Flywheel Pulley Lugs	99	2	199

The August, 1922, issue of data sheets for the S. A. E. HANDBOOK will be sent to the members early in October. It is important for members using the S. A. E. HANDBOOK in their work to check their books so that they may be sure that all, as well as the most recent, sheets issued to date have been inserted properly. A list of all the S. A. E. HANDBOOK pages and their latest publication dates is given on the first sheet of the August issue of data sheets. These dates should be checked to the dates under the emblems appearing at the bottom of each right-hand data sheet to verify the completeness and uptodateness of the S. A. E. HANDBOOK.

It should be borne in mind that the Contents is arranged so as to aid members in limiting their S. A. E. HANDBOOK to only those pages which are of interest, the standards being classified according to the automotive industries to which they apply by a system of key letters. Members interested, for instance, in only tractor engineering may want to retain in their books only those standards which are followed by the letter *T* in the Contents. The standards in the S. A. E. HANDBOOK may therefore be considered as being classified in the Contents in two ways; by parts and materials, such as powerplant and electrical equipment, the classifications being denoted by letters prefixed to the page numbers; and by automotive industries, the industries being denoted by letters appearing in the right-hand column in the Contents.

Activities of the Sections

THERE is every reason to believe that the Society is embarking upon one of its most successful Section years. It is evident from the meeting programs announced to date that the Section officers are selecting speakers of the first order and confining discussion to topics of specific interest. October opens the Section year in earnest. The schedule of meetings announced herewith includes every Section. The subjects are sufficiently diversified to reach all corners of the industry and in each case the papers are to be given by men of prominence in the respective fields.

Photographs of some of the Section Chairmen and Vice-Chairmen are reproduced on the facing page. The following list gives the name of the office and the Section for the various officers:

Name	*Office*	*Section*
A. H. Bates	Chairman	Minneapolis
O. C. Berry	Chairman	Indiana
T. F. Cullen	Chairman	Pennsylvania
K. K. Hoagg	Vice-Chairman	Detroit
B. S. Pfeiffer	Vice-Chairman	Mid-West
C. H. Warrington	Vice-Chairman	Washington

Buffalo Section

The Buffalo Section of the Society will open its season with a meeting on Oct. 18 at the Engineering Society Club Rooms in the Iroquois Hotel. L. H. Pomeroy, consulting engineer, will read a paper on Light Reciprocating Parts and Their Effect on Car Design. Mr. Pomeroy's contributions to the Society are always received with interest. It will be remembered that his experience was largely acquired in Great Britain where at one time he was chief engineer of Vauxhall Motors, Ltd.

Cleveland Section

The Cleveland Section will start its season with a meeting on Oct. 20. George M. Graham, vice-president of the Chandler Motor Car Co., will address the meeting on The Sales Manager and the Engineer. Mr. Graham is well known in the industry as an able speaker and a student of the automobile owner's tastes and demands. He is qualified to predict those changes in design that increase the sales appeal of the motor car and these are certain to impress the automotive engineer. There will be an organized discussion of this paper which is expected to contribute greatly to the value of the meeting. The Cleveland Section holds its meetings in the rooms of the Cleveland Engineering Societies, at the Hotel Winton, and they begin promptly at 8 o'clock.

Schedule of Sections Meetings

OCTOBER

3—Dayton Section—Some Problems Confronting the Automotive Engineer—C. F. Kettering

4—Minneapolis Section — Manufacture of Petroleum Products for Automotive Uses —N. S. Kingsley

5—Washington Section—A Road Test Method for Comparing Fuels—R. E. Carlson

11—Buffalo Section — Light Reciprocating Parts and Their Effect on Car Design—L. H. Pomeroy

12—Indiana Section—Trend of Research—C. F. Kettering

19—Metropolitan Section—The Modern Airplane and All-Metal Construction—William B. Stout

20—Cleveland Section—Sales Manager and the Engineer—George M. Graham

20—Mid-West Section—C. F. Kettering

26—Pennsylvania Section — Manufacture of Automobile Bodies

27—New England — Wire Wheels and Disc Wheels—O. J. Rohde

Dayton Section

The members of the Dayton Section will gather at the Dayton Engineers Club on Oct. 3 to hear C. F. Kettering, president of the General Motors Research Corporation, speak on Some Problems Confronting the Automotive Engineer. Mr. Kettering needs no introduction to the members of the Society. His broad experience and keen vision guarantee the presentation of much food for engineering thought. Few men are able to present scientific discussion in a manner that is both serious and entertaining. This C. F. Kettering can do and he is always assured an attentive and appreciative audience. This meeting will start at 8 o'clock and members from all Sections of the Society are welcome.

Detroit Section

The Detroit Section has not planned any special meeting for October because of the Society's Production Meeting that will be held in the General Motors Building on Oct. 26 and 27. The Section has taken an active part in the planning and arrangement of the Production Meeting. Its officers and members have been working diligently to make the program both interesting and instructive. It was largely due to the success of the Detroit Section's production meetings last spring that the Council decided to schedule this national meeting and to designate Detroit as its location. The Detroit Section welcomes the opportunity of entertaining the members of the Society from other parts of the Country and hopes that they will come in large numbers to the Production Meeting.

The September meeting of the Detroit Section was addressed by A. A. Bull, chief engineer of the Northway Motor & Mfg. Co. Mr. Bull abstracted the paper on Oil-Pumping that he read at the Summer Meeting of the Society last June. He also extended his discussion of the subject, adding experience gained subsequent to that meeting. The Section had arranged to have the paper discussed by a number of the leading automotive engineers of Detroit whose study of this problem qualified them to present information and data supplementing that given by Mr. Bull. The material presented in the discussion period added greatly to the interest and value of the meeting. Piston and ring design, lubrication systems, oil-pressures and crankcase-oil dilution all received consideration. It was generally agreed that the thorough treatment of aggravating troubles, such as oil-pumping, at Section meetings, led to a better general understanding of the controlling factors and enabled engineers to combat them to the benefit of the entire automotive industry.

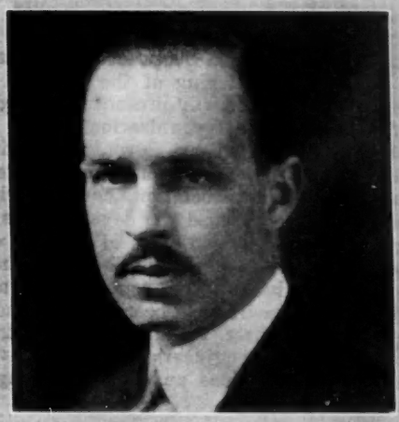
Metropolitan Section

W. B. Stout, president of the Stout Engineering Laboratories, Inc., Detroit, will present a paper on the Modern Airplane and All-Metal Construction before a meeting of the Metropolitan Section on Oct. 19. Mr. Stout has been engaged in the design and construction of all-metal monoplanes for the Navy during the past year. In this work he has developed structural shapes and methods for working duralumin that are a distinct advance in this field. Mr. Stout has long been an advocate of the internally trussed type of metal monoplane for commercial flying because of its decreased parasite resistance and increased durability. There

O. C. BERRY

BENJAMIN S. PFEIFFER

K. K. HOAGG



CHESTER H. WARRINGTON

A. H. BATES

T. F. CULLEN

seems to be a general tendency to adopt this type of airplaine, particularly abroad, and Mr. Stout's paper is expected to be of special interest for this reason. An informal dinner at 6:30 p. m. will precede the meeting which will be held at the Automobile Club of America, 247 West 54th Street, New York City, at 8 o'clock.

The Metropolitan Section Meeting of Sept. 21 resulted in a very lively discussion of lubrication systems. G. A. Round, who gave a paper on Oil-Pumping, contended that the problem was most serious in engines employing force-feed systems. The adherents of the force-feed scheme of lubrication naturally defended this design and considered it superior to the splash system. Finley R. Porter's paper outlined the advantages of the various systems of lubrication and this fitted in well with the discussion of Mr. Round's paper.

The members of the Metropolitan Section who attended the annual outing to West Point on Sept. 16 acclaimed in accord that they had an ideal trip. Everyone was curious to know how Mr. Bergmann bribed the weatherman for such perfect weather. Colonel Mettler supervised the inspection of the various buildings of the academy, after which dinner was served at the West Point Hotel. After dinner Mr. Bergmann introduced the new chairman of the Section, W. E. Kemp, who in turn introduced the honor guest of the day, President B. B. Bachman. The last speaker, Colonel Mettler, gave a very interesting address, outlining the work of West Point and stressing the democratic spirit that prevails there.

Indiana Section

The first meeting of the Indiana Section for the season will be held on Oct. 12. C. F. Kettering of the General Motors Research Corporation, Dayton, will present his predictions on the Trend of Research. The organization headed by Mr. Kettering is the largest of its kind devoted exclusively to commercial and scientific research along automotive lines. It is only natural that this association, coupled with Mr. Kettering's unusual ability to sense the developments of the future, should guarantee the presentation of thought deserving the attention of every member of the Society. There are few men more appreciative of the commercial value of research than Mr. Kettering. He has been a strong advocate of research ever since his first venture in the automotive industry. Several prominent engineers have been invited to discuss Mr. Kettering's predictions and an interesting meeting seems assured.

Minneapolis Section

The Minneapolis Section will open the season with a technical meeting on Oct. 4 at the Manufacturers Club. N. S. Kingsley will present a paper on the Manufacture of Petroleum Products for Automotive Uses. As the subject is very timely, a number of prominent engineers are expected to be present to discuss the important points of this paper.

New England Section

O. J. Rohde, vice-president of the Wire Wheel Corporation of America, Buffalo, will present a paper on Wire Wheels and Disc Wheels at a meeting of the New England Section on Oct. 27. Mr. Rohde has been associated with the wire wheel building industry for many years. He has made many exacting tests of wood, wire and steel disc wheels with a view to comparing their relative strength and effect upon tire wear. His talk will be illustrated with lantern slides and motion pictures. Opinion as to the most desirable type of wheel for automotive vehicles is at wide variance. Much of the discussion has been controversial but it is hoped that the quantitative data to be given by Mr. Rohde will clarify matters to a considerable degree.

L. B. Ehrlich gave an extremely interesting paper on automotive starting and lighting systems before the New England Section on Sept. 22. The meeting was attended by many of the electrical service-men in Boston and those in attendance were rewarded with an interesting outline of starting motor and generator characteristics. Mr. Ehrlich believed that engine designers should pay greater attention to the proper location of these electical units so that they would be more accessible for service purposes.

Pennsylvania Section

The first fall meeting of the Pennsylvania Section will be held in the rooms of the Engineers Club on Thursday evening, Oct. 26. The topic of the evening will be the manufacture of automobile bodies, particularly those of steel construction. It is expected that the address of the evening will be illustrated with slides showing bodies in the course of construction.

Washington Section

The Washington Section will start the Section year with a meeting on Oct. 5 at the Cosmos Club. R. E. Carlson of the Bureau of Standards staff, will present a paper on A Road Test Method for Comparing Motor-Fuels. Mr. Carlson is engaged in the conduct of the road tests now being run at the Bureau of Standards in connection with the Society's Fuel Volatility Research project. He will describe the methods and apparatus being employed in this work and give some idea of the conclusions that may be deduced from the data recorded. Mr. Carlson is associated with W. S. James, whose paper on road performance-testing aroused much favorable comment at the Summer Meeting. Members of the Society from other districts will be welcomed at this meeting, for it is recognized that the interest in the work at the Bureau is very widespread. The meeting will start at 8 o'clock.

Mid-West Section

The Mid-West Section meets for the first time this season on Oct. 20, in the rooms of the Western Society of Engineers in the Monadnock Building, Chicago. The meeeting will start at 7:30 o'clock. Here again we find our good friend, C. F. Kettering, announced as the speaker of the evening. Needless to say, Mr. Kettering's unusual presentation of any subject results in an incessant demand upon his speaking time. The members in the Mid-West district have not heard from him in some time and they prevailed upon him to open their series of Section meetings. The mechanical, civil and electrical engineers have been invited by the Section to participate in this meeting which assumes the character of a joint assembly.

TAP DRILL SIZES

A MEETING of the National Screw Thread Commission was held at the Bureau of Standards, at which consideration was given to the question of tap drill sizes to be recommended for producing holes in conformity with standards adopted by the Commission. It was voted to recommend drills of a diameter midway between the maximum and minimum minor diameters of the tapped holes already established. These limits result in a thread in the nut from 75 to 83⅓ per cent of the full depth, with a mean value of 79⅙ per cent of the full-thread depth. The recommended sizes are to be considered further with reference to a series of decimal wire gage sizes that is also under consideration.

Applicants *Qualified*

The following applicants have qualified for admission to the Society between Aug. 10 and Sept. 9, 1922. The various grades of membership are indicated by (M) Member; (A) Associate Member; (J) Junior; (Aff) Affiliate; (S M) Service Member; (F M) Foreign Member; (E S) Enrolled Student.

ALVUT, EDMOND JONES (E S) student, Rensselaer Polytechnic Institute, Troy, N. Y., (mail) 1116 Elm Street, *Utica, N. Y.*

ANDERSON, KENNETH B. (E S) student, California Institute of Technology, *Pasadena, Cal.*, (mail) 59 South Wilson Avenue.

BARNES, ORRIN HAYWARD (E S) student, California Institute of Technology, Pasadena, Cal., (mail) 910 East Harvard Street, *Glendale, Cal.*

BARTHOLOMEW, J. R. (J) assistant engineer, Westinghouse Pacific Coast Brake Co., Emeryville, Cal., (mail) 2612 Durant Avenue, *Berkeley, Cal.*

BLAKELEY, LOREN E. (E S) student, California Institute of Technology, Pasadena, Cal., (mail) 2013 East Florence Avenue, *Los Angeles, Cal.*

BORDEN, EDWARD ROY (M) mechanical engineer, Mudge & Co., 4425 West 16th Street, *Chicago.*

BREAKEY, EDWIN T. (J) factory superintendent, Columbia Carbureter Co., *Chicago,* (mail) 7024 Wentworth Avenue.

BREWER, HENRY (A) district sales manager, Leeds & Northrup Co., Philadelphia, (mail) 53 West Jackson Boulevard, *Chicago.*

BUELL, ROY D. (A) president, Buell Mfg. Co., *Chicago,* (mail) 2975 Cottage Grove Avenue.

CATE, GARTH W. (A) general manager, Flexo-Motive Corporation, *Chicago,* (mail) 551 McCormick Building.

DAVIS, FRED (A) engineering tests, General Motors Research Corporation, *Dayton, Ohio.*

DEMELTO, VINCENT MARION (E S) student, Ohio State University, Columbus, Ohio, (mail) 1614 Lake Front Avenue, *East Cleveland, Ohio.*

DOTY, E. M. (J) mechanical engineer, Denby Motor Truck Co., *Detroit,* (mail) 404 Lenox Avenue.

FAIRCHILD, SHERMAN M. (J) president, Fairchild Aerial Camera Corporation, New York City, (mail) 318 Main Street, *Oneonta, N. Y.*

GABBER, JACOB E. (E S) student, Ohio State University, Columbus, Ohio, (mail) 22 South Horton Street, *Dayton, Ohio.*

HANNAH, WALTER JOHN (F M) consulting engineer, Hannah, King & Co., *Glasgow, Scotland,* (mail) 209 Hope Street.

HAWLEY, B. T. (M) mechanical engineer, Holt Power Light Co., 4196 Bellevue Avenue, *Detroit.*

JACKSON, H. GARDNER (A) assistant general manager and sales manager, Wire Wheel Corporation of America, 1700 Elmwood Avenue, *Buffalo.*

JOHNSON, WILLIAM G. (J) 708 Sterling Avenue, *Joliet, Ill.*

KING, TOWER W. (J) airplane materials testing engineer, engineering division, Air Service, McCook Field, Dayton, Ohio, (mail) care L-W-F Engineering Co., *College Point, N. Y.*

KNERR, HORACE C. (S M) metallurgist, Navy Yard, *Philadelphia,* (mail) Naval Aircraft Factory.

KNIGHT, RALPH B. (A) superintendent of inspection, North East Electric Co., Whitney Street, *Rochester, N. Y.*

KOLB, GEORGE F. (A) manager of motorcycle division, Bullard Machine Co., Bridgeport, Conn., (mail) *Fairfield, Conn.*

LEWIS, MAJOR BURTON O. (S M) Office Chief of Ordnance, Ordnance Department, Room 3702, Munitions Building, *City of Washington.*

LUTZENBERGER, LOUIS D. (E S) 139½ South William Street, *Dayton, Ohio.*

MARSH, HALLAN N. (E S) student, California Institute of Technology, Pasadena, Cal., (mail) 1225 West Brookes Avenue, *San Diego, Cal.*

MILLER, H. S. (A) general manager, Plowman Tractor Co., *Waterloo, Iowa.*

PALMER, H. A. (M) chief engineer, Reynolds Spring Co., *Jackson, Mich.*, (mail) 1702 Francis Street.

PARROTT, R. B. (A) secretary and treasurer, Service Products Corporation, 201 South Rural Street, *Indianapolis.*

RICARDO, HARRY R. (F M) consulting engineer, Ricardo & Co., Ltd., Bridge Works, Shoreham, Sussex, England, (mail) *Penstone, Lancing, Sussex, England.*

ROOT, RALPH C. (M) engineer and sales manager, Service Products Corporation, 201 South Rural Street, *Indianapolis.*

ROUSE, GEORGE ALAN (J) assistant supervisor of motor vehicles, Standard Oil Co. of New Jersey, *Baltimore, Md.*, (mail) Y. M. C. A.

SAVANT, A. K. (J) student, University of Michigan, Ann Arbor, Mich., (mail) 2739 Second Boulevard, *Detroit.*

VAUGHAN, SAMUEL E. (E S) student, Leland Stanford, Jr., University, *Stanford University, Cal.*

WHITEHEAD, C. I. (A) P. O. Box 7187, *Johannesburg, South Africa.*

WITMER, GEORGE (A) branch manager, Sterling Motor Truck Co., Brooklyn, N. Y., (mail) 489 West 130th Street, *New York City.*

Applicants *for* Membership

The applications for membership received between Aug. 15 and Sept. 15, 1922, are given below. The members of the Society are urged to send any pertinent information with regard to those listed which the Council should have for consideration prior to their election. It is requested that such communications from members be sent promptly.

AIKEN, FRANK, ignition engineer, Atwater Kent Mfg. Co., *Philadelphia.*

BELL, JAMES L., general superintendent, Fulton Motors Corporation, *Farmingdale, N. Y.*

BOCA, JOSEPH, body engineer, Pierce-Arrow Motor Car Co., *Buffalo.*

BRIDWELL, J. W., chief engineer, Ruggles Motor Truck Co., *Saginaw, Mich.*

CAMPBELL, WILLIAM B., sales engineer, Nordyke & Marmon Co., *Indianapolis.*

CARLSON, RAYMOND A., draftsman, Rockford Drilling Machine Co., *Rockford, Ill.*

CARSON, RAY EDGAR, draftsman, Robert H. Hassler, Inc., *Indianapolis.*

DEN TEX, NICHOLAAS J., designer, Gallaudet Aircraft Corporation, *East Greenwich, R. I.*

EVENBURGH, R. L., designer, Advance-Rumely Co., *La Porte, Ind.*

FLOGAUS, HOWARD A., power transmission engineer, Willys-Overland Co., *Toledo.*

FOISY, GEORGE A., designing engineer, U. S. Cartridge Co., *Lowell, Mass.*

GAINES, WALTER S., assistant engineer, Rubay Co., *Cleveland.*

GERDES, HARRY, instructor in automobile mechanics, El Paso Public Schools, *El Paso, Tex.*

GILBERT, H. HOYT, research engineer, Cadillac Motor Car Co., *Detroit.*

HALL, G. P., Central district manager of manufacturers' sales, Westinghouse Union Battery Co., *Swissvale, Pa.*

HANNON, BOYD E., automotive engineer, Texas Co., *Chicago.*

HAYLETT, R. E., assistant manager, manufacturing department, Union Oil Co. of California, *Los Angeles, Cal.*

HECKMAN, J. A., treasurer, Heckman Signal Co., *Denver, Col.*

IRELAND, MAJOR MARK L., Quartermasters Corps, Massachusetts Institute of Technology, *Cambridge, Mass.*

KENNEDY, CAPT. GRAFTON S., Ordnance Department, *Aberdeen Proving Ground, Md.*

KIZER, H. W., automotive engineer, Texas Co., *Chicago.*

KREBS, HENRY, engineer of tests, Willys-Overland Co., *Toledo.*

LEA, R. W., executive vice-president and general manager, Stevens Motor Car Co., *Moline, Ill.*

MCQUAID, HARRY W., vice-president and chief engineer, National Pressed Gear Co., *Canton, Ohio.*

MARTY, MATHEW J., engineer, Chicago Mfg. Co., *Chicago.*

MILWARD, W. F., chief engineer, W. S. Laycock, Ltd., Millhouses, *Sheffield, Eng.*

OTT, T. F., superintendent lubricating division, manufacturing department, Union Oil Co. of California, *Los Angeles, Cal.*

PEASE, FRANK D., laboratory engineer, Studebaker Corporation of America, *Detroit.*

PORTER, ROLLAND COURT, designer, Prudden plant, Motor Wheel Corporation, *Lansing, Mich.*

PRICE, CHARLES S., chief engineer, Bethlehem Spark Plug Co., *Bethlehem, Pa.*

RAGSDALE, EDWARD T., draftsman, Pierce-Arrow Motor Car Co., *Buffalo.*

REDMANN, W. F. O., supervisor of motor vehicles, Municipal Garage, *Dayton, Ohio.*

SANFORD, ROY S., Sanford Fore-Wheel Brake Co., *Pasadena, Cal.*

WALLACE, DONALD E., experimental engineer, Shakespeare Co., *Kalamazoo, Mich.*

WATTS, WILLIAM SEWELL, student, Coyne Trade and Engineering School, *Chicago.*

WRIGHT, W. C., manager main line branch, John Warren Watson Co., *Philadelphia.*